THE

AMERICAN

JOURNAL OF SCIENCE.

EDITOR: EDWARD S. DANA.

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FOURTH SERIES

VOL. XXXVII—[WHOLE NUMBER, CLXXXVII].

WITH NINE PLATES.

NEW HAVEN, CONNECTICUT.

1914.

228784

THE TUTTLE, MOREHOUSE & TAYLOR COMPANY,
NEW HAVEN

CONTENTS TO VOLUME XXXVII.

Number 217.

Page

ART. I.—Determination of Mineral and Rock Densities at High Temperatures; by A. L. DAY, R. B. SOSMAN, and J. C. HOSTETTER 1

II.—Notes on a new occurrence of Pisanite and Arsenopyrite, and some large Staurolite Crystals from the Ducktown District, Tennessee; by F. R. VAN HORN 40

III.—Diagrammatic Representation of Volcanic Phenomena; by F. A. PERRET. (With Plates I to IV) 48

IV.—Nipa-palm in the North American Eocene; by E. W. BERRY 57

V.—Modification of the Usual Method of Correcting Silica for Included Salts; by S. B. KUZIRIAN 61

VI.—Electrometry with the Displacement Interferometer; by C. BARUS 65

VII.—Upper Devonian Delta of the Appalachian Geosyncline; by J. BARRELL 87

SCIENTIFIC INTELLIGENCE.

Chemistry and Physics—Behavior of the Radio-Elements in Precipitation Reactions, FAJANS and BEER: New Source of Gallium, BARDEL and BOULANGER, 110.—Ammonium Peroxides, D'ANS and WEDIG: Poison of Toads, WIELAND and WEIL: Quantitative Analysis in Practice, 111.—Constitution of Matter: Mechanics of Particles and Rigid Bodies, 112.—Elementary Treatise on Calculus, 113.

Geology and Natural History—Conemaugh formation in Ohio, 114.—Caradocian Cystidea from Girvan: A Contribution to the Paleontology of Trinidad, 115.—Formation of Coal Beds: Contributions to the Geology of the Nordingrå Region, 116.—West Virginia Geological Survey, County Reports, 1913.—Iowa Geological Survey: Permo-Carboniferous Vertebrates from New Mexico, 117.—The Meaning of Evolution, 119.—First Principles of Evolution, 120.—Geology and Ore Deposits of the San Francisco and Adjacent Districts, Utah: Nickel Industry, with Special Reference to the Sudbury Region, Ontario, 121.—Curious Lore of Precious Stones: Botanical Features of the Algerian Sahara: Wissenschaftliche Ergebnisse der Deutschen Zentral-Afrika-Expedition 1907–1908: Laboratory Manual and Notebook in Botany, 122.—Introduction to the Chemistry of Plant Products: Modern Problems of Biology: A Laboratory Manual of Invertebrate Zoölogy: Heredity and Memory, 123.—Bibliography of the Tunicata, 1469–1910: British Parasitic Copepoda; Copepoda Parasitic on Fishes: Weathering of Aboriginal Stone Artifacts, No. 1, 124.

Obituary—A. FRITSCH: H. POTONIÉ, 124.

Number 218.

Page

ART. VIII.—Geologic Reconnaissance of the Ayusbamba (Peru) Fossil Beds; by H. E. GREGORY 125

IX.—Vertebrate Fossils from Ayusbamba, Peru; by G. F. EATON. (With Plates V, VI, VII) 141

X.—The "Dam" at Cheshire, Connecticut; by F. WARD .. 155

XI.—Progressive Development of Mechanics based upon a New Form of Fundamental Principle of the Science; by H. M. DADOURIAN 157

XII.—Temiskamite, a new nickel arsenide from Ontario; by T. L. WALKER 170

XIII.—Use of the Ammonium Salt of Nitrosophenylhydroxylamine ("Cupferron") in the Quantitative Separation of Titanium from Iron; by W. M. THORNTON, JR. 173

XIV.—Contribution to the Optical Study of the Amphiboles; by W. E. FORD 179

SCIENTIFIC INTELLIGENCE.

Chemistry and Physics—Action of Aluminium Carbide upon Solutions of Metallic Salts, HILPERT and DITMAR, 193.—Solubilities at the Critical Temperatures of Solvents, F. FRIEDRICHS: Organic Chemistry for Advanced Students, J. B. COHEN: Industrial Chemistry for Engineering Students, H. K. BENSON, 194.—Outlines of Theoretical Chemistry, F. H. GETMAN: Oxygen in the Sun, RUNGE and PASCHEN, 195.—Fluorescence of the Vapors of Sulphur, Selenium and Tellurium, W. STEUBING, 196.—The Series Lines of Neon, R. ROSSI, 197.—Mass of Rapidly Moving Electrons, G. NEUMANN, 198.

Geology and Mineralogy—Changes in Level in the Earth's Crust, O. FISHER, 199.—Meteorites vs. The Earth, O. C. FARRINGTON, 200.—San Franciscan Volcanic Field. 202.—Devonian of Maryland: Stratigraphy and Paleontology of the Alexandrian Series in Illinois and Missouri, Part I, T. E. SAVAGE: Important part played by calcareous Algæ at certain geological horizons, E. J. GARWOOD. 203.—Geological Survey of Oklahoma: Minéralogie de la France et de ses Colonies, A. LACROIX: Handbuch der Mineralogie, C. HINTZE, 204.

Miscellaneous Scientific Intelligence—Semi-Centennial Anniversary of the National Academy of Sciences, 1863-1913, 204.—Annual Tables of Constants and Numerical Data, etc.: Fungi which cause Plant disease, F. L. STEVENS, 205.—Measures of Proper Motion Stars, S. W. BURNHAM, 206.—Astronomy, H. JACOBY: The American Chemical Journal, 207.

Obituary—S. W. MITCHELL: B. O. PEIRCE: S. C. CHANDLER: W. UPTON: C. B. ROBINSON: R. S. BALL: T. LAWRENCE: P. V. BEVAN: W. P. BLOXAM, 208.

Number 219.

Page

ART. XV.—Fossil Dolphin from California; by R. S. LULL. (With Plate VIII) 209

XVI.—Note on the Occurrence of the Oriskany Formation on Parlin Stream, Maine; by L. V. PIRSSON and C. SCHUCHERT 221

XVII.—Upper Devonian Delta of the Appalachian Geosyncline; by J. BARRELL 225

XVIII.—Paleogeographical Affinities of the Alexandrian Series; by C. KEYES 254

XIX.—Use of Telluric Acid in the Determination of Bromine associated with Chlorine in Haloid Salts; by F. A. GOOCH and H. ISABELLE COLE 257

XX.—Wilkeite, a New Mineral of the Apatite Group, and Okenite, its Alteration Product, from Southern California; by A. S. EAKLE and A. F. ROGERS 262

XXI.—Rocks of the Cerro de Santa Ana on Paraguana, Venezuela; by T. A. BENDRAT 268

SCIENTIFIC INTELLIGENCE.

Chemistry and Physics—Rusting of Iron in Water, W. A. BRADBURY: Estimation of Periodates in the Presence of Iodates and Iodides, MÜLLER and WEGELIN, 273.—Dictionary of Applied Chemistry, E. THORPE: Allen's Commercial Organic Analysis, W. A. DAVIS and S. S. SADTLER: Chemistry, Inorganic and Organic, C. L. BLOXAM, 274.—Quantitative Chemical Analysis, CLOWES and COLEMAN: Industrial Organic Analysis, P. S. ARUP: Radioactive Origin of the Color of Zircons, R. J. STRUTT, 275.—Suppression of the Photoelectric Effect, K. FREDENHAGEN and H. KÜSTNER, 276.—Effect of Temperature on X-ray Diffraction Patterns, DEBROGLIE, etc.: Measuring the Pressure Produced in the Detonation of High Explosives or by the Impact of Bullets, B. HOPKINSON, 277.

Geology and Natural History—Thirty-fourth Annual Report of the Director of the United States Geological Survey: Publications of the United States Geological Survey, 280.—Commission Internationale des Glaciers: Textbook of Paleontology, C. R. EASTMAN, 282.—Life of the Mollusca, B. B. WOODWARD: Victoria Memorial Museum, Bulletin No. 1, 1913, 283.—Atlas der Krystallformen, V. GOLDSCHMIDT: Paléontologie Végétale, F. PELOURDE: Fabre, Poet of Science, C V. LEGROS, 284.—Eleventh Annual Report of the Bureau of Science, Philippine Islands: Diseases of Tropical Plants, M. T. COOK, 285.

Miscellaneous Scientific Intelligence—Report of the Secretary of the Smithsonian Institution, 286.—Report of the Librarian of Congress, etc.: Catalogue of the Lepidoptera Phalænæ in the British Museum, Volume XIII, 287.—Napier Tercentenary Celebration: International Electrical Congress, 288.

Obituary—H. ROSENBUSCH: D. GILL: T. TCHERNYCHEFF, 288.

Number 220.

Page

ART. XXII.—The Rodadero (Cuzco, Peru),—A Fault Plane of Unusual Aspect; by H. E. GREGORY 289
XXIII.—Occurrence and Genesis of a Persistent Parting in a Coal Bed of the Lance Formation; by G. S. ROGERS. 299
XXIV.—About Climatical Variations; by H. ARCTOWSKI .. 305
XXV.—Late Paleozoic Glaciation in the Boston Basin, Massachusetts; by F. H. LAHEE 316
XXVI.—Note on the Use of the Wilson Tilted Electroscope; by H. W. FARWELL 319
XXVII. — Mammut Americanum in Connecticut; by C. SCHUCHERT. With a note on the Farmington specimen by R. S. LULL 321
XXVIII.—Hydrolysis of Esters of Substituted Aliphatic Acids; by E. W. DEAN 331
XXIX.—Solid Solution in Minerals. V. The Isomorphism between Calcite and Dolomite; by H. W. FOOTE and W. M. BRADLEY 339

SCIENTIFIC INTELLIGENCE.

Chemistry and Physics—Fused Magnesium Chloride as a Crystallizing Agent, K. A. HOFMANN and K. HÖSCHELE, 345.—Carbon Sulphide-Telluride and Carbon Sulphide-Selenide, A. STOCK, P. PRAETORIUS, and E. WILLFROTH: Double Bromides of Gold, A. GUTBIER and J. HUBER, 346.—Gravimetric Determination of Selenium, J. MEYER: Active Nitrogen, E. TIEDE and E. DOMCKE: Rays of Positive Electricity and their Application to Chemical Analyses, J. J. THOMSON, 347.—Photo-Electricity, H. S. ALLEN, 348.—Introduction to the Mathematical Theory of Attraction, F. A. TARLETON: Chemistry of the Radio-elements, Part II, F. SODDY: Modern Seismology, 349.—Alternating Currents and Alternating Current Machinery: Mutual Repulsion of rigid Parallel Plates separated by a Film of Air, C. BARUS, 350.

Geology and Mineralogy—Third Annual Report of the Director of the Bureau of Mines, 351.—Canada Department of Mines, 352.—Report of Topographic and Geologic Survey Commission of Pennsylvania, 1910–1912, 353.—Graphite Deposits of Pennsylvania, B. L. MILLER: Geological Survey of New Jersey: Geologic Atlas of the United States, Niagara Folio, New York, E. M. KINDLE and F. B. TAYLOR: Union of South Africa, Mines Department, Annual Reports for 1912, 354.—Inter-State Conference on Artesian Water: The Ocean: General Account of the Science of the Sea, J. MURRAY.—Descriptions of Land, R. W. CAUTLEY: Interpretation of Anomalies of Gravity, G. K. GILBERT: Mud Lumps at the Mouths of the Mississippi, 356.—La Face de la Terre, E. SUESS: Water and Volcanic Activity: Zeitschrift für Vulkanologie, 357.—Igneous Rocks and their Origin, R. A. DALY, 358.—Bergalite, 359.—Notices of recently described Minerals, 360.

Miscellaneous Scientific Intelligence—Carnegie Institution of Washington, 361.—Annual Report of the Superintendent of the United States Coast and Geodetic Survey: Newcomb-Englemanns Populäre Astronomie, 363.—Milton's Astronomy, The Astronomy of Paradise Lost, T. N. ORCHARD: Trigonometry, A. M. KENYON and L. INGOLD, 364.—Who's Who in Science, International, 1914: Franklin Institute award of the Elliott Cresson Medal: The Cambridge Manuals of Science and Literature: Tables and other Data for Engineers and Business Men, C. E. FERRIS, 365.

Obituary—J. MURRAY: E. S. HOLDEN: W. W. BAILEY: G. MERCALLI: A. GÜNTHER: H. B. WOODWARD: A. R. CLARKE, 366.

Number 221.

Page

ART. XXX.—Reef Formations of the Northeast Coast of Brazil; by G. A. WARING. (With Plate IX) 367

XXXI.—Note on a New Meteoric Iron from Mount Edith, Ashburton District, West Australia; by W. M. FOOTE. 391

XXXII.—Occurrence of Molybdenum in Rocks with special reference to those of Hawaii; by J. B. FERGUSON 399

XXXIII.—Fruits of a Date Palm in the Tertiary Deposits of Eastern Texas; by E. W. BERRY 403

XXXIV.—Separation of Titanium from Iron, Aluminum, and Phosphoric Acid with the Aid of the Ammonium Salt of Nitrosophenylhydroxylamine ("Cupferron"); by W. M. THORNTON, JR. 407

XXXV.—New Features in the Geology of Northwestern Spitzbergen; by O. HOLTEDAHL 415

XXXVI.—Permian Geology of Northern Brazil; by M. A. R. LISBOA 425

XXXVII.—Finger Lake Bed in Ashland and Wayne Counties, Ohio, with Tilted Shore Lines; by G. D. HUBBARD 444

XXXVIII.—Remnants of an Old Graded Upland on the Presidential Range of the White Mountains; by J. W. GOLDTHWAIT 451

XXXIX.—The Shawangunk Conglomerate and Associated Beds near High Falls, Ulster County, New York; by T. C. BROWN 464

SCIENTIFIC INTELLIGENCE.

Chemistry and Physics—Peculiarity of Nickel and Cobalt Sulphides, A. THIEL and H. GESSNER: Dimethyl Phosphates of the Rare Earths, J. C. MORGAN and C. JAMES, 475.—Qualitative Chemical Analysis, A. VORISEK: Introduction to Modern Inorganic Chemistry, J. W. MELLOR, 476.—Practical Methods of Organic Chemistry, L. GATTERMANN: Spectrography of Röntgen Rays, M. DE BROGLIE, 477.—Removal of the Photoelectric Effect of Potassium, HALLWACHS and WIEDMANN, 478.—Heat of Formation of Hydrogen from Hydrogen Atoms, I. LANGMUIR: Thermal Expansion of Quartz Glass, K. SCHEEL and W. HEUSE, 479.—Physics for Technical Students; Mechanics and Heat, W. B. ANDERSON: Natural Sources of Energy, A. H. GIBSON, 480.—Effect on the Propagation of Electric Waves of the Total Eclipse of the Sun, 21st August, 1914, 481.

Geology and Natural History—Manual of Petrographic Methods, A. JOHANNSEN, 482.—History of Land Mammals in the Western Hemisphere: Nomenclature of certain Starfishes, A. E. VERRILL, 483.—Birds of Connecticut, Bulletin No. 20, J. H. SAGE, L. B. BISHOP, and W. P. BLISS, 484.—Letters and Recollections of Alexander Agassiz, with a Sketch of his Life and Work, G. R. AGASSIZ, 485.

Obituary—G. W. HILL: G. M. MINCHIN: J. H. POYNTING: A. SALINAS, 486.

Number 222.

Page

ART. XL.—The Binary System MgO–SiO_2; by N. L. BOWEN and OLAF ANDERSEN 487

XLI.—Application of the Displacement Interferometer to the Horizontal Pendulum; by C. BARUS 501

XLII.—Hydrolysis of Esters of Substituted Aliphatic Acids; by W. A. DRUSHEL 514

XLIII.—Thermochemistry and the Periodic Law. Heats of Combination; Linear Functions of the Atomic Weights of Related Elements; by W. G. MIXTER 519

XLIV.—Picking Out and Mounting Diatoms; by J. M. BLAKE 535

XLV.—Chemical Composition of Bornite and its Relation to Other Sulpho-Minerals; by E. H. KRAUS and J. P. GOLDSBERRY 539

SCIENTIFIC INTELLIGENCE.

Chemistry and Physics.—Relative Abundance of Several Metallic Elements, F. W. CLARKE and G. STEIGER, 553.—Spitting of Silver, H. B. BAKER: Laboratory Guide to the Study of Qualitative Analysis, E. H. S. BAILEY and H. P. CADY, 554.—Chemistry in America, E. F. SMITH: Annual Reports of the Progress of Chemistry for 1913, 555.—Progress of Scientific Chemistry in Our Own Times, W. A. TILDEN: Synthetic Use of Metals in Organic Chemistry, J. HALE: Electrical Analogue of the Zeeman Effect, J. STARK, 556.—Secondary Standards of Wave-Length in the Infra-Red, A. IGNATIEFF: Electrical Conductivity and Ionization Constants of Organic Compounds, H. SCUDDER, 558.—Theory of Heat Radiation, M. PLANCK, 559.

Geology—Virginia Geological Survey, 559.—Florida State Geological Survey: Illinois Geological Survey: Ohio and Mississippi Floods of 1912, H. C. FRANKENFIELD: New Zealand Geological Survey, 560.—Mountains; their Origin, Growth, and Decay, J. GEIKIE, 561.—La Geographié de Terre-Neuve. R. PERRET: Fossilium Catalogus: Spitsbergen Map of Prince Charles Foreland from Surveys, W. S. BRUCE, J. MATHISON, etc., 562.

Miscellaneous Scientific Intelligence—National Academy of Sciences, 562.—Carnegie Foundation for the Advancement of Teaching; Eighth Annual Report of the President, HENRY S. PRITCHETT, 563.—Carnegie Foundation for the Advancement of Teaching; Education in Vermont, 564.—Mining World Index of Current Literature, G. E. SISLEY: Les Prix Nobel en 1912: Manual of Bacteriology, H. S. REED, 565.

Obituary—N. H. WINCHELL: C. S. S. PEIRCE: E. SUESS: J. HUBER: R. K. GRAY.

The American Journal of Science

ESTABLISHED BY BENJAMIN SILLIMAN IN 1818.

THE LEADING SCIENTIFIC JOURNAL IN THE UNITED STATES.

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WITH PLATES I–IV.

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THE TUTTLE, MOREHOUSE & TAYLOR CO., PRINTERS, 123 TEMPLE STREET.

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ART. I.—*The Determination of Mineral and Rock Densities at High Temperatures;* by ARTHUR L. DAY, R. B. SOSMAN, and J. C. HOSTETTER.

1. *Existing Data.*

BEFORE discussing briefly the existing data on the change of specific volume with temperature, we shall mention several misinterpretations and misunderstandings which have occasionally appeared.

In the first place, the sharp distinction between a glassy and a crystalline substance has not always been kept in mind. A glass is essentially a liquid which has cooled without crystallization to a point where its viscosity has become so great as to give it the mechanical rigidity of a solid without the addition of any new property. The cooling has resulted in no release of the heat of fusion, nor has it developed a discontinuity in any physical or chemical property. There has therefore been no change of state (freezing point) and no one temperature which possessed more physical significance than another in the entire process of cooling to the temperature of the surroundings. The same is true of the reverse operation; inasmuch as the glass acquired no new property on cooling, it has none to give up on reheating, and there is no melting and no melting temperature. We must, therefore, associate glasses with "liquids," not with "solids."

By definition, the temperature at which crystals of a substance (the "solid" phase) will exist indefinitely in contact with their "liquid," unless heat is added or withdrawn, is the true melting temperature of the substance. Above it the liquid alone is stable, and below it only the crystals are stable. But if the substance be very inert it may exist for very long periods in the temperature region in which it is not stable (as, for ex-

ample, in the form of a cold glass), and the properties characteristic of the substance in the form stable at this temperature may thereby be completely veiled.

In passing from the amorphous or glassy condition over to the crystalline condition a compound usually undergoes a sudden change of specific volume. It is obvious that with rising temperature a glass might increase in specific volume continuously, and perhaps at the same time irregularly, in softening gradually to its normal liquid state; yet the fact would indicate nothing as to the amount or even the direction of its specific volume change in passing from the amorphous (liquid) state to the crystalline state.

In the second place, it should be noted that a rock, which is nearly always a mixture or solid solution, behaves very differently from a single chemical compound. The single compound *melts* at a definite temperature, whether its liquid be viscous or not, in accord with the above definition; the rock liquefies, continuously or in distinct steps according to the thermal characteristics of its individual components, and through a range of temperature which may be very wide. We cannot speak, then, of the "volume change on melting" of a rock as though it were a specific property, but only of the "volume changes between the temperatures t_1 and t_2." With rising temperature, some of these changes of specific volume may be positive, some negative; some will occur at one temperature, some at another; and the total between temperatures t_1 and t_2 may be an increase or a decrease.

Indirect Estimates.—The most of the estimates of the volume changes in rocks solidifying from an amorphous state are drawn indirectly from the specific gravities at 20° of the glassy and the crystalline rock respectively.* In general, the specific volumes of silicate glasses at 20° have been found to be greater than those of crystalline solids of the same composition. Hence if the dilatation coefficients of the solid and the glass are nearly equal, the rock may be assumed to have undergone a net expansion in liquefying.

Estimates made from this standpoint are subject to several large uncertainties. The unknown rate of volume dilatation with increasing temperature, and the frequent changes in this rate through inversions in the solid state, are large unknown factors. Then, too, the glass sometimes cools with the inclosure of fine gas bubbles which make its volume appear too

* A. Harker, Natural History of Igneous Rocks, p. 158, 1909. F. Zirkel, Lehrb. d. Petrogr., i, p. 680-685, 1893. A. Delesse, Recherches sur les Verres provenant de la Fusion des Roches, Bull. Soc. Geol. France (2), iv, 1380, 1847. J. A. Douglas, On changes of physical constants which take place in certain minerals and rocks on the passage from the crystalline to the glassy state, Quart. Jour. Geol. Soc., lxiii, 145–161, 1907.

large, while on the other hand the process of fusion frequently changes the original composition by driving off water or other volatile constituents, a change which may lead to an apparently smaller volume for the glass than for the crystal.

There are a few cases known of natural glasses which are denser than the corresponding rocks. It is not altogether certain, however, that this is not due to small differences in composition. Thus, Delesse* found that the glassy portion of certain basic dikes in Scotland was from 1·5 to 4 per cent denser than the crystalline portion.

In general, it may be said that if the glass has a considerably greater volume than the crystalline solid (10 per cent or more), it is fairly certain that the solid will expand in liquefying. But as a basis for comparing the volume at high temperatures of one type of rock in the crystalline state with another type of rock in the molten state, the volumes at ordinary temperatures are quite unreliable.

Evidence that is even more indirect than the comparison of volumes at ordinary temperature has been offered by other authors. Some of these have supported a supposed general expansion of rocks in crystallizing. For instance, Lang† in 1875 concluded, from microscopic observation of basalt in comparison with gypsum, that jointing of rocks is due not to contraction but to the pressure developed by expansion during solidification. Stübel‡ has based a theory of volcanicity upon such a supposed expansion. This same theory was put forth by Bornemann in 1887.§ He found experimentally that melanite crystals inclosed in leucite can be fused without disturbing the leucite, and that the fused silicate cools to a glass containing bubbles or vacuoles, indicating that the glass occupies a smaller volume than the original crystal.‖ The amount of the contraction was estimated to be 4 per cent.

On the other hand, Gilbert, in 1877,¶ estimated that the trachyte of the Henry Mountains had contracted by about one-tenth of its volume from the liquid to the cold crystalline state. This estimate was based on the densities of the sedimentaries and on the hypothesis that the horizon of the laccolitic intrusions was determined solely by the relative densities of the liquid magma and the invaded rocks.

* Delesse, Ann. Mines (5). xiii, 369, 1858.

† Jahresh. d. Ver. f. Vaterländ. Naturk. in Württemburg, xxxi, 336, 1875.

‡ A. Stübel: Die Vulkanberge von Ecuador, p. 367–376, Berlin, 1897.

§ J. C. Bornemann: Ueber Schlackenkegel und Laven. Koenigl. Preuss. geol. Landesanst, Jahrb., 279, 1887.

‖ Ibid., p. 252–258.

¶ Geology of the Henry Mountains, p. 72–80. (U. S. Geographical and Geological Survey Rocky Mt. Region, 1877.)

Direct Measurements.—In addition to the estimates obtained by these indirect methods, direct measurements of the volume change accompanying the liquefaction of rocks and minerals have been attempted. The most of these have depended: (1) upon the floating or sinking of a solid body in the molten rock; (2) upon direct measurement of the volume changes in a given mass of molten material.

Observations are on record of the floating or sinking of lava crusts in liquid lava and of the floating of solid bodies thrown into lava lakes.* The data are contradictory and unsatisfactory. The floating of lava crusts is usually due to their spongy, porous structure; in the lava lake of Kilauea, for instance, these crusts sink rapidly when freed from their entrapped or supporting gases.

Flotation experiments on a small scale, with molten rocks, artificial silicates, or metallurgical slags, have also yielded contradictory results. Whitley,† in 1878, concluded from such experiments that there is contraction in the liquefying of basalt and of iron-furnace slags. Doelter,‡ in 1901, from the sinking or floating of solid bodies of various densities, concluded that there is a net expansion in the liquefying of melanite, augite, and several rocks, and estimated its amount. As no account seems to have been taken of the expansion of the test substances, the results have little quantitative value. Doelter later improved the method by using a platinum sphere;§ he estimates from measurements made with the new apparatus that the density of liquid diopside near its melting point is 2·8. Fleischer‖ takes the opposite view, that lavas expand in solidifying; his arguments, drawn from a variety of laboratory data of a rather indirect kind, are unconvincing.

Nies and Winkelmann¶ obtained no satisfactory results by the flotation method. The earlier literature is well summarized in their articles, which, however, are concerned chiefly with metals.

Measurements of the actual expansion or contraction of molten slags and lavas began with Bischof** about 1838. He estimated a total contraction of from 10 to 25 per cent in passing from the molten to the cold crystalline condition, in basalt, trachyte, and granite. Similar measurements were made by

* See F. Zirkel, Lehrb. d. Petrogr., i, 684, 1893.

† Nature, xviii, 397, 1878.

‡ Neues Jahrb. Min., 1901, II, 141–157.

§ Doelter and Sirk, Sitzb. Wien. Akad., cxx, i, 659–670, 1911.

‖ A. Fleischer, Zeitschr. Deut Geol. Ges., lv, 56–68, 1903; lvii, 201–214, 1905; lxix, 122–131, 317–321, 1907; lx, 254–258, 1908.

¶ F. Nies and A. Winkelmann, Ann. Phys. (2), xiii, 43–83, 1881. F. Nies, Über d. Verhalten d. Silicate beim Übergang aus dem gluthflüssigen in den festen Aggregatzustand, Stuttgart, 1889.

** Neues Jahrb. Min., 565, 1841; 1–54, 1843.

Forbes,* Mallet,† and Barus,‡ all of whom observed contraction in passing from liquid to solid. Joly used a novel method§ in observing the expansion of spherical beads of different mineral glasses with rising temperature, by projecting the magnified image of a bead on a screen. All of these measurements have been open to the serious criticism mentioned in a preceding paragraph, that the substances cooled partly or wholly to glass; the measurements therefore did not include (or only partly included) the change of state liquid-solid concerning which information was sought.

The measurements by Barus were probably the best up to that time, and have been so frequently quoted that they deserve further description. His method consisted in completely filling a platinum tube with melted diabase,‖ and following the downward movement of the surface, as the melt cooled, by means of a platinum contact point carried by a cathetometer outside of the furnace.

By preliminary fusion in the open air, Barus found that the melted diabase cooled to a glass without crystallizing. He states, therefore, that "throughout this paper the molten rock solidifies into an obsidian."¶ On the basis of his own statements it has therefore been assumed that he really did not observe the volume change accompanying the passage from liquid to crystalline, and the irregularity which he undoubtedly did observe has remained an unexplained anomaly. But, as we shall see later, the rock really crystallized in part under the conditions of slow cooling within his platinum tube, and the sudden volume change which he observed at about 1095° represents a part of the difference in volume between crystalline and glassy rock at that temperature.

According to Barus' figures, the difference in specific volume between diabase and diabase glass at 20° is 11 per cent of the volume of the crystalline rock. At about 1100° he found a contraction of 3·9 per cent in the glass.**

Barus also observed that on reversing the measurements and heating the rock until fluid, the volume change was more gradual and came at a higher temperature than the contraction on solidification. The reason for this will become clear from our own experiments.

* D. Forbes, Chem. News, p. 6, 1868.

† R. Mallet, Phil. Trans., clxiii, 147–227, 1873.

‡ C. Barus, U. S. Geol. Survey Bull., ciii, 25–44, 1893.

§ J. Joly, Trans. Roy. Soc. Dublin (2), vi, 283–304, 1847.

‖ The rock is described as "a typical diabase obtained from Mr. Clarence King" (then Director of the U. S. Geological Survey). No information as to its origin was published. It appears to have come from the Palisade diabase along the Hudson River.

¶ Loc. cit. (Bull. ciii), p. 26; also pp. 25, 36.

** Loc. cit., p. 41.

2. *Method and Apparatus.*

After consideration of the experimental difficulties and the opportunities for error in the few methods available for density determinations at high temperatures, we adopted the method of Archimedes, namely, weighing the displacement of a liquid of known density. The principal difficulty, as with all investigations at high temperatures, is with materials of construction. Those used finally were graphite, which in a reducing atmosphere retains its form indefinitely, Marquardt porcelain, which does not soften appreciably below 1600°, and alundum (Al_2O_3), which melts at about 2050°, but is very porous. Pure magnesia is also available, but lacks mechanical strength and permanence.

The liquid to be used should have the following properties: (1) high boiling point, (2) low melting point. (3) low volatility between these temperatures, (4) high density, (5) no chemical reaction with graphite, (6) no action on the minerals to be examined. Silver and tin best fulfil these conditions. Tin has the advantage over silver of a very low melting point (232°), and the disadvantage of lower sensitiveness because of its lower density.

The substance to be investigated, being always lighter than the metal, was contained in an inverted graphite crucible. The measurement consisted in determining the weight necessary to immerse the crucible and material to a given depth on the stem of the crucible. Because of the gases given off by natural rocks and minerals when heated, both the liquid metal and the containing crucible must be such as to release these gases (or imprisoned air) at once. Imprisoned gas bubbles would destroy the significance of the measurements. The success of the particular form of apparatus used therefore depends upon the permeability of graphite to these gases. As noted above, the use of a graphite crucible requires the maintenance of a reducing atmosphere within the furnace.

In the form of apparatus first tried, the weight was applied at the top of a long porcelain stem projecting upward from the crucible through the top of the furnace. But the center of gravity of this system was too high, with the result that to prevent tilting guides were required, which introduced too much friction. The weight was therefore applied below (fig. 1), by means of a cage surrounding the large crucible containing the metal.

The fixed level to which the float-crucible was immersed was found by electrical contact. A circuit from a storage cell through a galvanometer entered the bottom of the furnace and made connection with the graphite crucible containing the

metal by means of a graphite rod (R in fig. 2), held always in contact with the bottom of the crucible by a spring at its lower end. The other terminal from the cell connected, through the pan on which the weights were placed, with the graphite cage, which carried a pointed pin (A in fig. 1) on its upper cross-bar. The circuit was complete through the galvanometer when the graphite point touched the surface of the metal. This arrangement required that the inverted float-crucible should be insulated from the cage, and also that the cage should not touch the large crucible containing the metal.

Fig. 1 is a section of the apparatus as used, showing how these requirements were met. G is the inverted graphite float-crucible, containing a block (S) of the substance to be examined. F is the graphite cage or frame. The platinum wire P hangs from the lower cross-bar of this frame through a small hole (H in fig. 2) in the bottom cover of the furnace, and on its lower end is hung a copper[1] or aluminum pan, W, for the weights. The stem (B) on the upper cross-bar of the cage allows cage and crucible to be lifted free of the liquid metal before its solidification at the end of the measurements, by means of a hook let down from above. The float-crucible is insulated from the cage by the ring of magnesia (E), and the whole is pinned together by two graphite pins about a millimeter in diameter, so that the float can be lifted up with the cage. Magnesia was here used instead of porcelain, because the latter yielded slowly at high temperatures to the constant bending stress exerted by the crucible stem.

Fig. 1.

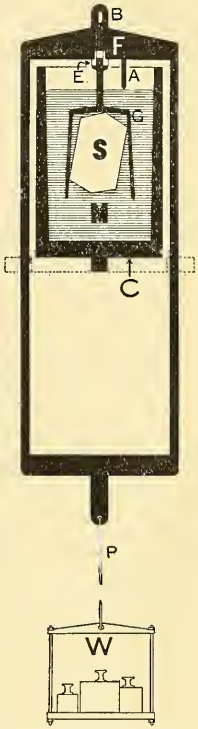


Fig. 1. Graphite apparatus for determining the volume of solid and liquid silicates.

The crucible, C, containing the metal, was held upon a column of tubes and screens of Marquardt porcelain or alundum, locked together so as not to get out of alignment. The lowest tube stood upon three set screws (D, fig. 2) by which the column could be adjusted vertically until the float and cage swung free. Similar screens above the crucible prevented loss of heat by radiation upward.

The temperature was measured by a platinum platin-rhodium thermo-element inclosed in a glazed Marquardt tube, which was immersed in the metal close to the side of the crucible in

FIG. 2.

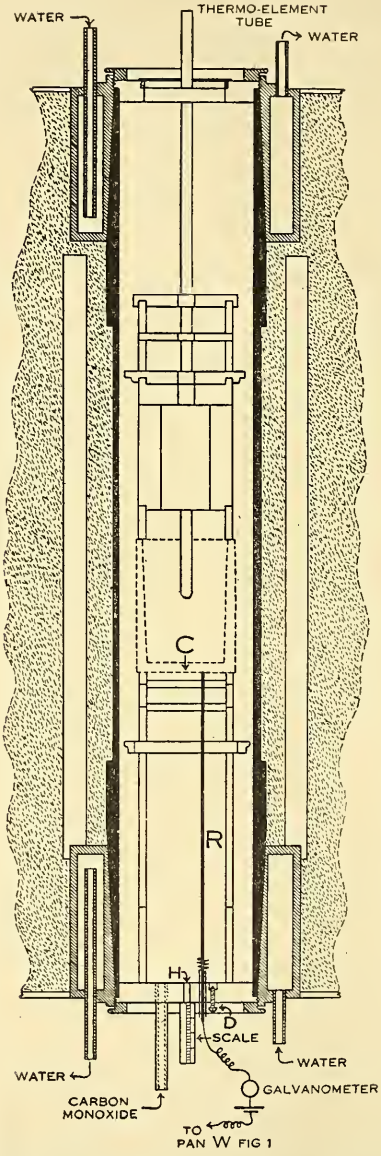


FIG. 2. Carbon-tube electric furnace for apparatus of fig. 1.

order not to interfere with the float. The e.m.f. of the element was measured in terms of a standard cadmium cell with the help of a Wolff potentiometer. The readings were converted to degrees on the standard temperature scale, in the manner described in recent publications from this laboratory.*

The opening H (fig. 2) was kept closed by a plug of asbestos, except for a few seconds while making the measurements, in order to maintain the reducing atmosphere within. The admission of a small amount of air at this point cannot be avoided, however, and to prevent its oxidizing the lower crossbar of the cage, this was covered with a thin sheet of platinum. The loss of weight from the cage during a series was then less than 0·1 gram. This was corrected for in the calculations.

The furnace required for this apparatus must give a uniform temperature up to 1600° in a space about 80^{mm} in diameter and 200^{mm} long. For this purpose the carbon tube furnace shown in fig. 2 was employed. It was built on the same plan as our small tube-furnace used for the melting point of platinum,† except that only the middle portion of the tube was of carbon, ground on the lathe to a uniform thickness and diameter. This was set into end pieces of graphite which fit the brass water-cooled terminals and require no copper plating or soldering to give a good contact. The carbon tube was surrounded by a fireclay tube, and the intervening space filled with carborundum. The outside packing was of petroleum coke. This furnace took about 750 amperes at 10–15 volts to reach 1600°.

After the earlier measurements the apparatus was enlarged to obtain greater sensitiveness. The second furnace was of the granular carbon resistance type, developed at the Koenigliche Porzellan-Manufaktur in Charlottenburg.‡ The heated zone in this furnace was about 130^{mm} in diameter and 250^{mm} long.

The graphite apparatus was protected from oxidation by a mixture of nitrogen and carbon monoxide, introduced through a tube at the bottom. This gas mixture was made by passing air through a porcelain or iron tube filled with coke and standing vertically in a nickel wire resistance furnace kept at about 1100°. Only 18 grams of coke are required to furnish 100 liters of gas containing two parts nitrogen and one part carbon monoxide. The gas was passed through suitable

* Day and Sosman, this Journal, xxix, 93–161, 1910. R. B. Sosman, ibid., xxx, 1–15, 1910. Day and Sosman, Carnegie Institution Publ., No. 157, 1911.

† Sosman, this Journal, xxx, 1–15, 1910.

‡ J. Bronn, Der Elektrische Ofen, p. 94, 1910.

absorbing agents to remove traces of carbon dioxide, hydrogen sulphide and water vapor.

3. *Preliminary Measurements.*

The first datum necessary is the density or volume curve of the metal up to the highest temperature to be used. As an absolute basis for determining this volume, we must have the measured linear or volumetric expansion of some solid substance up to the same temperature. The only one available seemed to be amorphous silica (quartz glass), whose expansion has been determined by several investigators, and is, furthermore, so small as to be almost negligible. We sought to employ this known datum by making two series of measurements: first, the displacement of metal by a solid graphite float; second, the displacement of metal by a similar float in which as much as possible of the graphite was replaced by some silica glass disks, cut from a block of glass made by Day and Shepherd in this laboratory. A series of simultaneous equations was thus obtained, containing the density of silver and the expansion coefficient of graphite as unknown quantities.

Although this series gave the density of silver within 0·5 per cent, the results were not entirely satisfactory, first because the silica glass crystallized to cristobalite at about 1200°, cutting off the measurements at that temperature; and second, because too much uncertainty was left in the expansion coefficient of the graphite, which was required to be used in later work as a correction. Therefore, direct determinations were made of the expansion of the graphite used, and these were taken as the basis for the volume determinations on the metals.

4. *Expansion of Graphite.*

The data on the expansion coefficient of Acheson artificial graphite, together with a comparison and discussion of results, have already been published elsewhere.* The measurements were made on bars about 700^{mm} long, in two types of electrically heated furnaces. The mean coefficient of expansion from 0° is expressed by the formula

$$10^6\beta = 0{\cdot}55 + 0{\cdot}0016\,t.$$

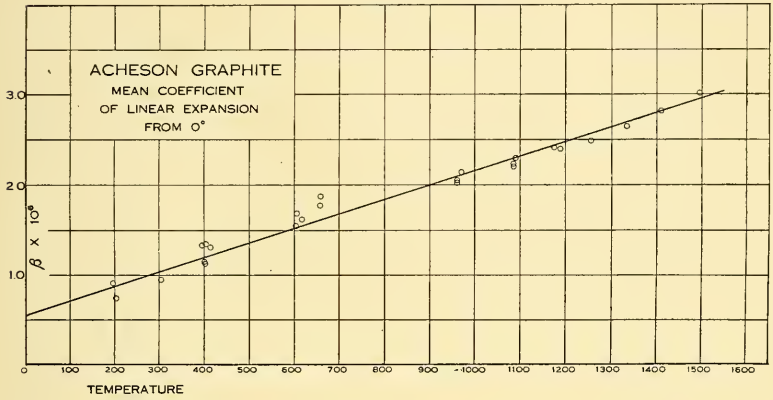
The actual determinations are plotted in fig. 3.

To obtain an accuracy of 0·1 per cent in the specific volume of tin, the expansion coefficient of graphite needs to be known with an accuracy of only 7·5 per cent at 1500°, and of 40 per

* A. L. Day and R. B. Sosman, Jour. Ind. Eng. Chem., iv, 490–493, 1912; Jour. Washington Acad. Sci., ii, 284–289, 1912.

cent at 500°. The effect of errors in the expansion coefficient upon the measured volume of the metals was therefore extremely small. The effect of a similar error upon the measured volume of minerals was even smaller, because only a crucible or shell of graphite of small volume was employed.

FIG. 3.



5. *Specific Volume of Metals Used.*

It is hardly worth while to record the large number of observations made on silver, tin, lead, the eutectic of tin and lead, and other lead-tin alloys. The data on silver and the alloys are not complete, and as the values do not enter into the volumes of any substances discussed in this paper, they will be reserved for later publication. The experimental results on tin, lead, and the lead-tin eutectic are plotted in figs. 4 and 5. These include three series on tin (11, 26, and 28 October 1910), three on lead (30 June 1911, 13 March 1912, 31 January 1913), and one on the eutectic (16 June 1911). The eutectic contains 63 weight per cent of tin, 37 of lead.*

The volumes and densities at round temperatures are summarized in Table I.

The curves of figs. 4 and 5 have been completed between 0° and our lowest temperatures of measurement by inserting the data of Vicentini and Omodei. In the case of lead their value for the density at the melting point is apparently too low, and we have put in Table I the value obtained by extrapolating our own curve over the very short interval of 11° between our measurements and the melting point.

The volume curve for tin is very nearly a straight line from

* Bornemann, Metallurgie, viii, 271-275, 1911.

FIG. 4.

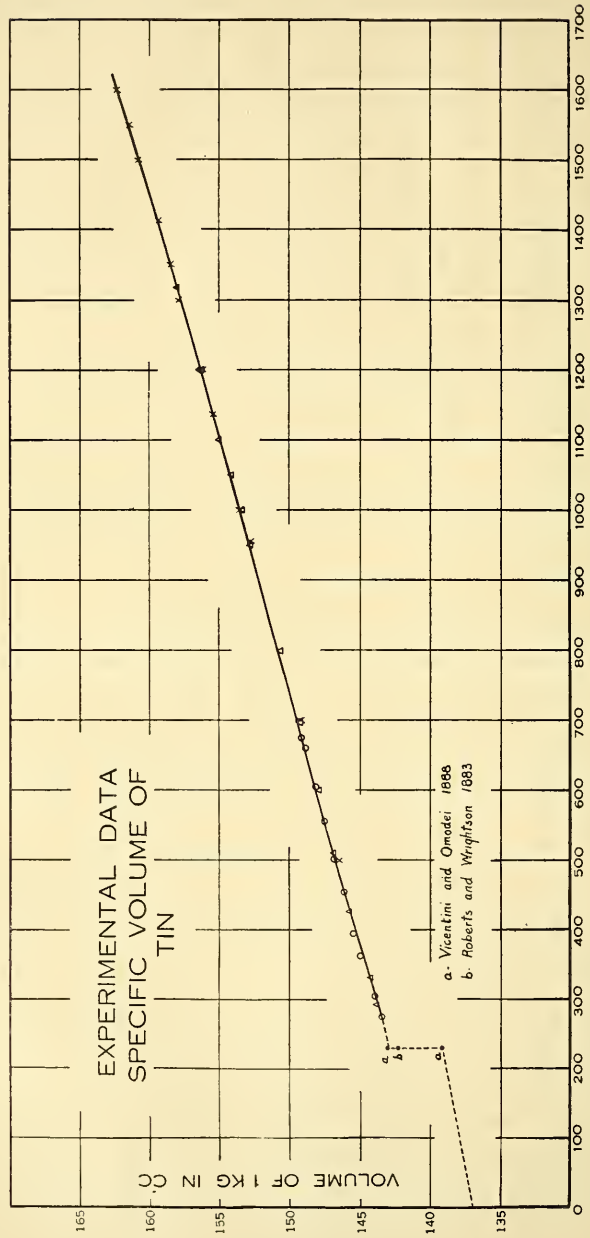
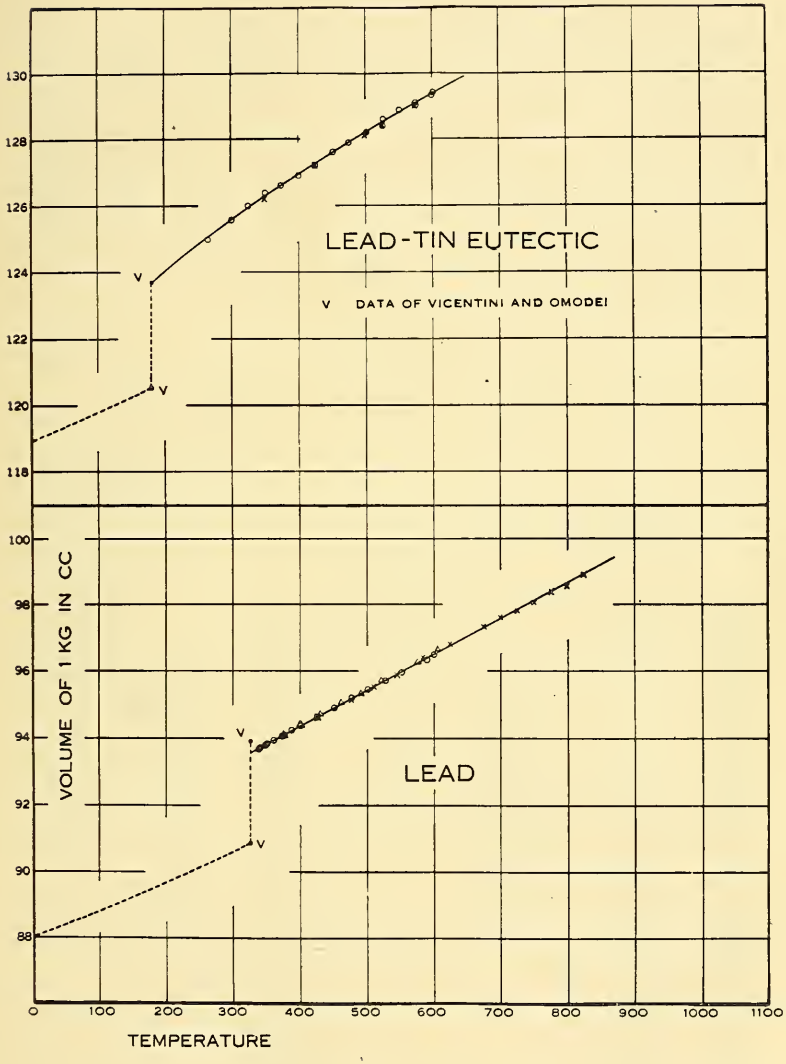

EXPERIMENTAL DATA
SPECIFIC VOLUME OF
TIN
VOLUME OF 1 KG IN C.C.
TEMPERATURE
a. Vicentini and Omodei 1886
b. Roberts and Wrightson 1883
a
b
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
135
140
145
150
155
160
165

FIG. 5.


LEAD-TIN EUTECTIC
V DATA OF VICENTINI AND OMODEI
LEAD
VOLUME OF 1 KG IN CC
TEMPERATURE
130
128
126
124
122
120
118
100
98
96
94
92
90
88
0
100
200
300
400
500
600
700
800
900
1000
1100

the melting point up to 1600°, but is slightly concave upward. The graph for lead is perfectly straight from the melting point to 825°, and is represented by the formula:

$$\text{Kilogram-volume} = 90{\cdot}05 + 0{\cdot}0108\,t.$$

The curve for the eutectic is slightly concave downward.

At 650° the kilogram-volume of the eutectic, calculated on the assumption that the volume is proportional to the weight-percentage, should be 129·6. The value actually found, 129·88, is only 0·2 per cent higher than this. The difference might easily be brought about by the combined errors of compounding the alloy and making the three separate determinations of volume. In other words, the mixing of the two liquid metals in eutectic proportion is not accompanied by any contraction or expansion in the total volume.

TABLE I.

Density and Volume of liquid tin, lead, and lead-tin eutectic.

Temp.	Density			Kilogram-Volume		
	Tin	Lead	Eutectic	Tin	Lead	Eutectic
181			(8·082)*			(123·7)
200			(8·063)			(124·0)
232	(6·988)*			(143·1)		
250	(6·982)		8·011	(143·2)		124·83
300	6·943		7·965	144.03		125·55
327		10·686			93·58	
350	6·908	10·658	7·921	144·76	93·83	126·25
400	6·875	10·597	7·879	145·45	94·37	126·92
450	6·844	10·536	7·838	146·11	94·91	127·58
500	6·814	10·477	7·800	146·76	95·45	128 20
550	6.785	10·418	7·764	147·38	95·99	128·79
600	6·755	10·359	7·731	148·04	96·53	129·34
650	6·725	10·302	7·699	148·70	97·07	129·88
700	6·695	10·245		149·37	97·61	
750	6·666	10·188		150·02	98·15	
800	6·637	10·132		150 67	98·69	
850	6 607	10·078		151·35	99·23	
900	6·578			152·02		
950	6·548			152·72		
1000	6·518			153·42		
1100	6·459			154·82		
1200	6·399			156·27		
1300	6·340			157·73		
1400	6·280			159·24		
1500	6·221			160·75		
1600	6·162			162·29		

*Vicentini and Omodei. Atti R. Acc. Lincei. iii, pp. 235, 294, 321, 1887.

6. *Quartz.*

A considerable amount of data already exists on the expansion of quartz. Fizeau* and Benoit† have determined its linear expansion, both parallel and perpendicular to the optic axis, with great accuracy below 100°. Reimerdes‡ has extended the parallel coefficient to 220°, and Randall§ to 500°. Le Chatelier‖ made approximate measurements on both axes up to 1060°, at a comparatively small number of temperatures.

The quartz which we used was all from Minas Geraes, Brazil, and was in the form of clean transparent blocks weighing from 35 to 85 grams.

Measurements were made up to 1602° under metallic tin, in the inverted crucible apparatus described on page 7. Check measurements were also made in another form of apparatus designed for lower temperatures and for solid blocks only.

This apparatus consisted of a cage similar in form to the graphite cage, but made of monel metal¶ (a nickel-copper alloy). The graphite float-crucible was replaced by a four-pronged metal clasp which held the block of quartz. The crucible containing the metal was of steel. The furnace was wound with platinum wire.

Measurements were made with this apparatus, using the molten eutectic of tin and lead, the density of which had been determined by means of a graphite block.

The individual determinations are too numerous to be reproduced here. Table II, giving the results of one of the series, will suffice to show the order of magnitude of the quantities measured, and the precision.

The first column gives the temperature, and the second the total displacement, which is equal to the sum of the weights of the sample, the graphite crucible and cage, the pan, and the added weights. The third column gives the density of liquid tin at the temperature in question, and the fourth column the resulting volume of tin displaced. Subtracting the volume of the graphite crucible in column 5 gives the volume of the sample, and dividing this by the mass of the sample gives the specific volume in the last column. For convenience this is multiplied by 1000, so that the figures represent the "kilogram-volume" or volume of one kilogram in cubic centimeters.

* Pogg. Ann., cxxviii, 564–589, 1866.
† Trav. Mem Bur. Int., vol. vi, 1888.
‡ Inaug. Diss. Jena, 1896.
§ H. M. Randall, Phys. Rev., xx, 10–37, 1905.
‖ H. LeChatelier, Compt. rend., cviii, 1046–1049, 1889.
¶ Steel, which was used at first, is too magnetic, and a small error is introduced on account of the force exerted by the furnace current.

TABLE II.

Example of Determinations of Specific Volume of Quartz.

Date ..... 21 January, 1911
Weight of specimen ..... 34·12 g.
Weight of cage, etc. ..... 94·17 g.
Volume graphite crucible at 0° ..... 8·21 cc.
Metal used ..... Tin.

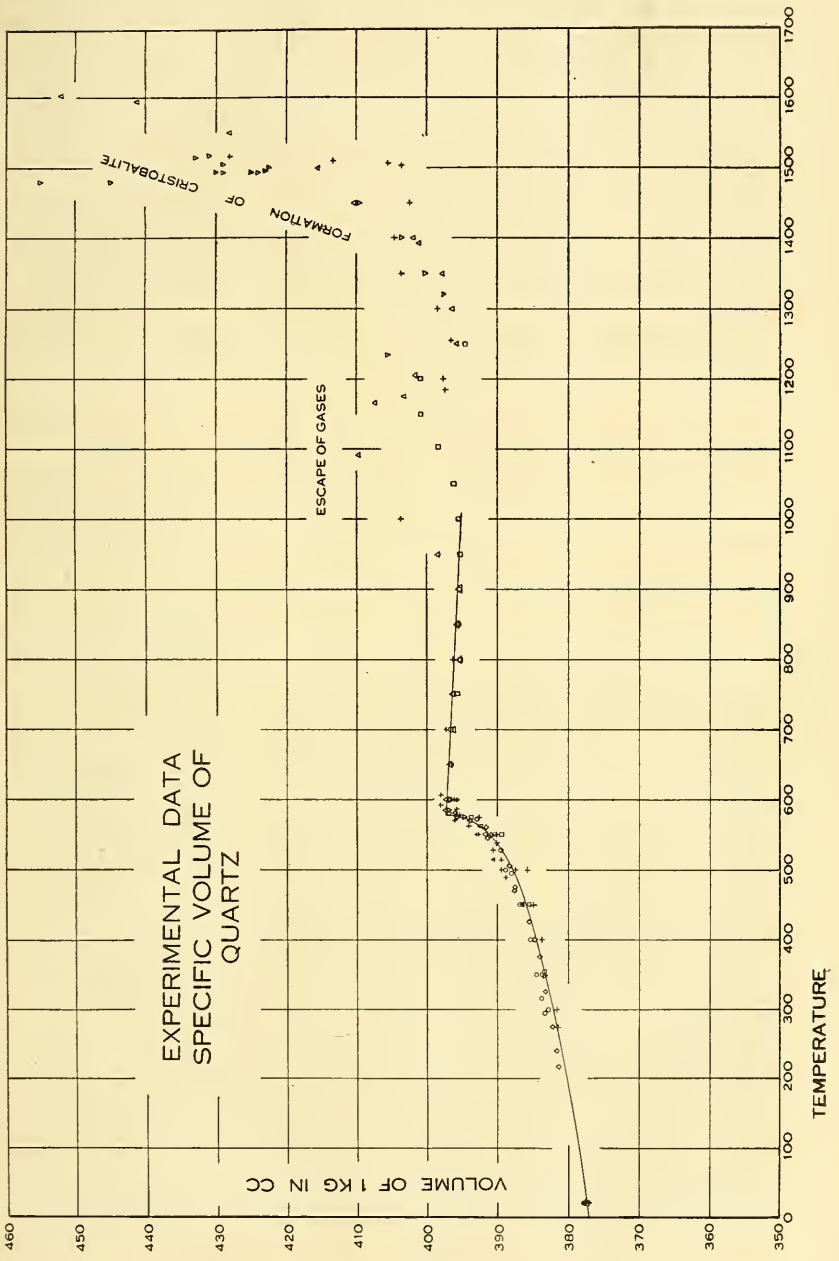
Temp.	Total wt.	Dens. tin	Total volume	Volume graphite.	Volume quartz	Kilo-volume quartz 1000 *v.*
20	----	----	---	----	12·877	377·5
450	146·6	6·844	21·42	8·23	13·19	386·6
514	146·7	6·806	21·55	8·23	13·32	390·5
550	146·5	6·785	21·59	8·23	13·36	391·6
561	146·5	6·778	21·61	8·23	13·38	392·2
585	147·3	5·764	21·78	8 23	13·55	397·2
600	147·1	6·755	21·78	8·23	13·55	397·2
650	146·4	6·725	21·77	8·24	13·53	396·6
701	145·6	6·694	21·75	8·24	13·51	396·0
755	145·0	6·663	21·76	8·24	13·52	396·3
800	144·3	6·637	21·74	8·25	13·49	395·4
850	143·7	6·607	21·75	8·25	13·50	395·7
900	143·0	6·578	21·74	8·25	13·49	395·4
950	143·1*	6·548	(21·85)	8·26	(13·59)	(398·4)
1091	143·8†	6·464	(22·3)	8·27	(14·0)	(410·)
1167	142·3†	6·419	(22·2)	8·28	(13·9)	(407·)
1175	141·3†	6·414	(22·0)	8·28	(13·7)	(403·)
1204	140·6†	6·397	(21·98)	8·28	(13·7)	(402·)
1250	138·8‡	6·370	21·79	8·29	13·50	395·7
1300	138·3	6·340	21·81	8·29	13·52	396·3
1350	138·0	6·310	21·87	8·30	13·57	397·8
1392	138·2	6·285	21·99	8·31	13·68	401·0
1400	138·3	6·280	22·02	8·31	13·71	401·9
1450	139·4	6·250	22·30	8·31	13·99	410·1
1500	139·9	6·221	22·49	8·32	14·17	415·4
1550	142·0	6·192	22·93	8·33	14·60	428·0
1594	144·2	6·166	23·39	8·34	15·05	441·2
1602	146·4	6·161	23·76	8·34	15·42	452·0

* Gas evolution beginning. † Gas escaping rapidly. ‡ Gas evolution ceased.

The volumes of the float-crucible and of the quartz at 20° were determined by replacing the molten tin by mercury. The volume of the sample was also checked by weighing under water in the usual manner.

All of the experimental data on quartz are plotted in fig. 6, and the six series of measurements are listed in Table III. As will be seen from the curve, the volume increases more and more rapidly as the inversion temperature (575°) is approached. Beyond that temperature the volume seems to decrease slightly. The escape of gases beyond 950° interrupts the measurements, and the points shown in the figure represent merely chance

FIG. 6.


EXPERIMENTAL DATA
SPECIFIC VOLUME OF
QUARTZ
ESCAPE OF GASES
FORMATION
OF
CRISTOBALITE
VOLUME OF 1 KG IN CC
TEMPERATURE
460
450
440
430
420
410
400
390
380
370
360
350
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700

values of apparent volume due to the fact that the gas escapes from the quartz more rapidly than it can get out through the graphite float-crucible. But above 1250°, when the evolution of gas had practically ceased, there are a few points which indicate that the volume either continues constant or goes on diminishing over the range from 950° to 1250°. About this time, however, the formation of cristobalite becomes rapid and the volume begins to increase greatly.

The form of curve below 575° is not due to a time lag. No effect due to the rate of heating was noticed, and the volumes obtained on lowering the temperature were practically the same as with rising temperature, except for a small increase (about 0·2 per cent) due to the formation of a few cracks at the inversion temperature. Data with both rising and falling temperatures are included in fig. 6.

TABLE III.

Measurements made on Minas Geraes Quartz.

Date	Metal.	Wt. of specimen	Mark in Fig. 6
9 January, 1911	Tin	43·98	Circle
18 " "	"	same	Square
21 " "	"	34·12	Triangle
13 February "	"	35·02	Cross
21 " "	"	39·96	Inverted triangle
20 June "	Tin-lead eutectic	85·18	Diamond

The form of curve which we have found for the volume increase up to 575° is somewhat different from that calculated and published by LeChatelier.* His determinations below 575° were at three temperatures only, and the volumes calculated from his linear expansions at those temperatures fall almost exactly on our curve. Above 575° his values for the volume are too low, probably because his measurements were made (photographically) on bars 100^{mm} long. With the ends exposed, as they must have been, a considerable percentage of the length may never have reached the transition temperature with its accompanying large increase in length.

The increasing dilatation of quartz as the temperature approaches 575° is especially striking when compared with the curves for various other properties. Among those properties on which accurate measurements to 500° or higher have been made are the following: linear expansion parallel to the axis,

* LeChatelier, Compt. rend., cviii, 1046–1049, 1889. Bull. Soc. Fr. Min., xiii, 112–118, 1890.

crystal angles (F. E. Wright, unpublished), double refraction, refractive index parallel and perpendicular to the axis, and specific heat. While some of these properties are interdependent, nevertheless it is a striking fact that in every case the effect of the change at 575° begins to be felt 200° or more below the temperature of complete inversion.

All of these various properties agree in showing a sudden break in the curve at 575°. In other words, although each property shows a rapidly increasing effect due to the approaching inversion, nevertheless there is apparently a discontinuity in the low-temperature branch of the curve. The final stage of the transition occurs very rapidly, probably within 0·1°, a range of temperature too small to be controlled and measured with our present forms of apparatus. This final part of the curve should therefore be drawn as a vertical straight line. The optical data show this point better than do the volume data.

The form of the quartz curve is not that which would result from the presence of two molecular species in equilibrium, of which the one is increasing in concentration at the expense of the other. It is rather the form of curve which would result from the action of opposing mechanical forces.

Various mechanical models of such a system will suggest themselves. For instance, the curve showing the relation between the angular velocity and the moment of the forces on two co axial cylinders rotating in water has a discontinuity like that in the quartz curve, since there is a limiting value of the velocity below which the moment is proportional to the velocity, and above which the square of the velocity enters.

The quartz curve therefore tends to confirm the view, well stated by Fenner in his article on the forms of silica,* that the alpha-beta inversions of quartz and tridymite represent only a rearrangement of the molecules in the crystal, whereas the change from one of these forms to another represents a real change in the constitution of the molecule itself.†

The unusually small variation in the properties of the high temperature quartz with rising temperature is also striking. It is pertinent to inquire whether there may not be some connection between this fact and the unusually slow time-rate of melting of quartz. In both of these respects it differs from almost all other known solids. Orthoclase shows an interesting parallelism in being, on the one hand, one of the slowest-melting of the silicates, and, on the other, in having one of

* This Journal, xxxvi, 365, 1913.

† Since the above was written, F. E. Wright has published a comparison and discussion of the quartz curves. Jour. Washington Acad. Sci., iii, 485–494, 1913.

the lowest dilatation coefficients, actually contracting in two directions while expanding in the third.* A great deal of additional work on the properties of matter in the solid state is necessary before these relationships can be understood.

Escape of gases from quartz.—As the data of fig. 6 show, there was a rapid escape of gases from the quartz, beginning at about 950° and continuing for a varying period of time depending upon the rate of heating. We made no attempt to find the lowest temperature at which this gas evolution would begin, nor did we study the effect upon the gas evolution of holding the quartz for a long time at a fixed temperature.

Chamberlin† has found that the average amount of gas obtained from six specimens of quartz was 0·35 of the volume of the crystal, and that the gases consisted chiefly of carbon dioxide and hydrogen. The amount of gas obtained by simply crushing the mineral to open the microscopic cavities was insignificant, even from quartz having comparatively large cavities. The amount obtainable by chemical reactions of water and impurities in the quartz was also small. The greater part of the gas seemed therefore to be either in solution in the solid crystal, or held in invisible cracks.

Our experience supports this view. Quartz heated to 1300° under tin, after giving off a considerable quantity of gas above 1000°, was brought back to room temperature with relatively few cracks and with unimpaired transparency. The cracking seems usually due to the rapid volume change as the temperature approaches 575°.

The volume of gas escaping from our quartz specimens was, however, much greater than the volumes stated by Chamberlin. It should be noted that the gases collected by Chamberlin were all passed over calcium chloride before any measurements were made, so that he has no data on the amount of water vapor evolved nor on the temperature at which it escaped.

A. W. Wright‡ found that the smoky quartz of Branchville, Connecticut, contained, on the average, 0·062 per cent water which escaped below red heat, in addition to 1·32 volumes of gas chiefly carbon dioxide.§ This quartz contained unusually large inclusions filled with water and liquid carbon dioxide. Koenigsberger and Mueller‖ found that 80 to 90 per cent of the included material in three Alpine quartzes was water.

* Fizeau, Pogg. Ann., cxxxv, 372–395, 1868.

† R. T. Chamberlin: The Gases in Rocks, Carnegie Institution Pub. 106, 1908.

‡ This Journal (3), xxi, 209–216, 1881.

§ Wright's figure has been quoted erroneously as "0·07 volume" in Chamberlin's table (p. 24 of Publication 106).

‖ Centralblatt Min., 72–77, 1906.

The Brazilian quartz used in our experiments showed under the microscope no trace of gas bubbles or inclusions. 8·37 grams (in large fragments) heated for a few minutes at 620° lost 1·8^{mg} or 0·022 per cent. Heated further for 2½ hours at 1105°, the quartz lost 0·3 milligram additional, or 0·025 per cent in all. If this were all water vapor at 1000°, it would have a volume about 3·7 times that of the quartz. In contact with graphite this volume might be doubled by the formation of hydrogen and carbon monoxide. Such a volume of gas would be sufficient to account for the phenomena observed. This question was not pursued further as it would lead us too far astray from our present purpose, and as it presents a large problem for further work.

Formation of cristobalite.—Fenner* has shown in this laboratory that quartz is the stable form of silica under atmospheric pressure only up to 870°. From 870° to 1470° tridymite is stable, and above 1470°, cristobalite. Quartz in the dry state will not pass directly into tridymite between 870° and 1470°, but above 1000° it will be converted directly, though slowly, into cristobalite. At 1300° this conversion is fairly rapid.

As will be seen from the curves of fig. 6, the volume begins to increase noticeably above 1300°. In the series of 21 January, 1911, with a maximum temperature of 1602°, cristobalite formed a surface layer over the block about half a millimeter thick, and had also grown into the larger cracks, causing considerable cracking and distortion of the block and increasing its apparent volume about 15 per cent. This block was above 1400° for about 40 minutes. In the series of 13 February, 1911, considerably more cristobalite had formed, and the block was easily broken to pieces; this had been above 1400° for 65 minutes. In the series of 21 February the block was held at 1500° for about 3½ hours. The conversion to cristobalite was still quite incomplete, although the chalky white growth of crystals had penetrated all through the block. In every case the cristobalite formed first on the exposed surfaces, and grew inward, so that even in the most completely converted block there were clear unaltered fragments weighing a gram or more in the center of the block, and microscopic unaltered angular quartz scattered all through the converted portions.† The apparent volume increase in this last case amounted to 52 per cent. On account of the friable and porous character of the cristobalite formed, however, this is considerably larger than

*C. N. Fenner, Jour. Washington Acad. Sci., ii, 471–480, 1912; this Journal, xxxvi, 331–384, 1913.

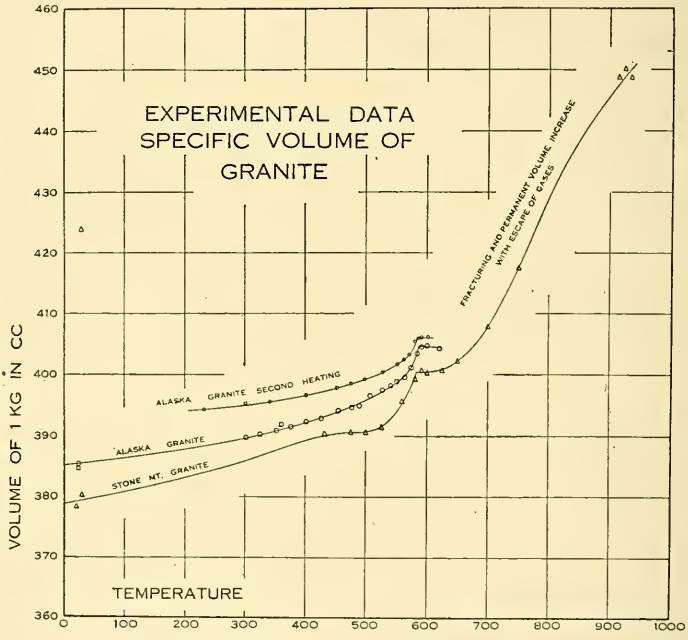
† This dependence of the growth of cristobalite upon the surface exposed has been noted by Endell and Rieke, Zs. anorg. Chem., lxxix, 239–259, 1912.

the true increase. At 20° the true specific volume of cristobalite is 13·4 per cent greater than that of quartz.

7. *Granite.*

Three specimens of granite were used: (1) a hornblende granite from Copper Mt., Alaska (No. 128); (2) a pink coarse-grained quartzose granite from Kasaan Peninsula, Alaska (C. W. Wright No. 39); (3) a gray biotite-muscovite granite from Stone Mountain, Georgia. The latter was furnished us

FIG. 7.



in the form of two large blocks by the Stone Mt. Granite Co. of Atlanta.

The first specimen was used only for a preliminary measurement. The second was tested under tin to 618° in the metal-frame apparatus (page 15). The third was tested to 935° in the graphite apparatus. The results are plotted in fig. 7.

In both of the granites that were heated above 575°, the rapid volume increase on approaching that temperature is notable. This increase is to be expected from the presence of free quartz in the granite, but its amount is unexpectedly

large. The volume increase of the two granites between 0° and 575° is 5·07 and 5·82 per cent, respectively, giving a mean of 5·45 per cent. The corresponding increase for pure quartz is 5·17 per cent.

The most probable cause of this abnormally large expansion is the action of the pure quartz crystals in pushing the other mineral fragments apart, increasing the apparent volume of the rock. Evidence for this explanation is seen in the curve giving the data of a second heating of the Alaska granite. In this series the volumes are all larger, although the curve is parallel to the first. The final kilogram-volume of this rock after the two heatings to 600° was 393·7, a permanent increase of 2·20 per cent.

In the Stone Mt. granite, which was heated to 935°, a very considerable permanent expansion occurred. This is probably due largely to the unequal expansion of the different minerals, which causes them to push each other apart, fracturing the rock and rendering it porous and friable. The relative dimensions of the block, after heating, remained the same, but it had increased in volume by 9·3 per cent.

The heating above 575° caused also the evolution of considerable gas between the temperatures 750° and 900°. During a part of the time the gas was evolved quite regularly, causing the floating system to rise and fall rhythmically, this rise and fall being caused by gas accumulating, lifting the float crucible, and escaping through the graphite top. Chamberlin found in the Stone Mt. granite 0·76 of its volume of gas, consisting chiefly of hydrogen. Water, which he did not determine, would add considerably to this, just as in the case of quartz already discussed (see p. 21). The escape of these gases probably contributes to the shattering and permanent dilatation.

This permanent dilatation in granite and other rocks has frequently been noted by other observers, and is indeed to be expected in any heterogeneous material. Any change of temperature will cause the constituent parts to expand unequally in accordance with their differing dilatation coefficients, and if the temperature range is large enough so that the stresses thus set up exceed the breaking strength of the parts, there will be internal fracturing and opening of irregular cavities.

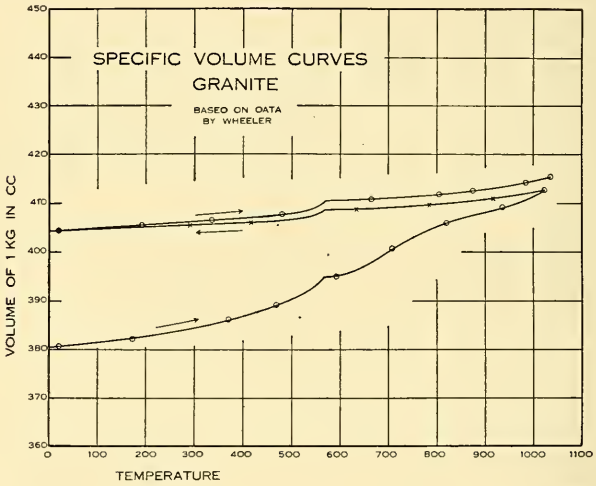
N. E. Wheeler* has determined the linear expansion of several rocks used by Adams and Coker in their high pressure studies. In all cases a considerable permanent expansion was produced by the first heating. We have calculated from his data the volumes of the Westerly (Rhode Island) granite

* Trans. Royal Soc., Canada, iv, III, 19–44, 1910.

which he used, on the basis of a specific gravity of 2·627 at room temperature.* The results are plotted in fig. 8.

These expansion measurements by Wheeler were made on a 20-centimeter bar of rock the ends of which were viewed through side openings in the furnace tube. This method would tend to cover up any irregularities in the expansion, since the portion near the ends of a heated bar may lag in temperature considerably behind the remainder of the specimen, even under conditions of stationary temperature. We

Fig. 8.



have found this to be true in a similar apparatus in which measurements were made on platinum alloys.† On account of this temperature gradient, the effect of a transformation which is complete at a definite temperature may be spread over a considerable range of temperature. The break in curvature near 575° is therefore much less marked than in our own curves. It is noticeable, however, especially on Wheeler's cooling and reheating curves for the same block.

Under the conditions above noted, there would have been no purpose in carrying on the experiments to a temperature sufficient to liquefy the granite, since the true dilatation of the crystalline rock can not be determined. Under the heavy pressure of overlying rocks the dilatation due to fracturing and differential expansion would be less than that obtained in ex-

* Datum from F. D. Adams, private letter, 1913.

† Day and Sosman, this Journal (4), xxvi, 425–441, 1908; xxix, 114, 1910; Carnegie Inst. Publ. 157, pp. 35, 63.

periments at atmospheric pressure, but it would become zero only at depths where the minerals would flow or redissolve and fill all pore spaces.

8. *Diabase.*

The diabase used was from the quarry of the Fairview Stone Crushing Company, near Granton, N. J. The diabase exposed at this locality appears to be an offshoot of the great Palisades sheet which outcrops along the Hudson River and southwestward through New Jersey. The particular specimen in question, in the form of a 100 lb. block, was from the lower contact of the diabase against the underlying Newark (Triassic) shale and sandstone.

Prof. J. Volney Lewis, who collected this material for us, has described the rock in his report on the "Petrography of the Newark Igneons Rocks of New Jersey."* At the locality in question there was, until quarrying operations followed it back into the underlying strata, an excellent example of a type of inclusion frequently occurring in the Palisade diabase, namely, slabs of the underlying shale or arkosic sandstone which have been "floated" up into the igneous rock. These occur in various parts of the sheet and stand at various angles between horizontal and vertical.†

It was therefore of interest to compare the volume of the molten diabase with that of the solid arkose and shale at the same temperature.

Our experience with granite had already convinced us that the expansion of a complex rock can not be accurately determined by direct measurement above a few hundred degrees, because of the shattering due to the unequal expansion of the different minerals. Furthermore, a trial series on a pyroxenite showed that when the rock was heated up directly through its fusion range, its volume change in liquefying was concealed by the escape of a large amount of gas, which swelled the half-melted pasty rock into a sponge so voluminous as to cause the tin to overflow and thus spoil the series of measurements.

We therefore made a glass of the rock by fusion in the open air, thus permitting the escape of all bubbles, followed by rapid cooling. The rock was fused in a cylindrical crucible made of platinum foil $0{\cdot}05^{mm}$ thick; the foil was then stripped from the glass when cold, leaving a block of the proper dimensions.

Each melt was held for a few minutes between 1300° and 1350° until all bubbles had escaped from the liquid. When

* Geol. Surv. New Jersey, Ann. Rept. 1907, 97–168. See in particular, plate XVI; analyses V and XII, p. 121, and p. 127.

† Ibid., p. 135 and plate XXVII, fig. 2.

cold it formed a clear dark brown glass, with a refractive index varying from 1·59 to 1·61. No bubbles were visible, even under the microscope, and no crystalline material except at a few points on the surface of the block. These were cut away by grinding.

It was to be expected that this fusion would not only drive off the water but would also cause some change in the state of oxidation of the iron, so that the glass would not retain exactly the composition of the original rock. The amount of moisture was found to be very small (see Table IV). The amount of change in the iron was determined analytically, and is shown in Table IV. For the present approximate determinations of the volume change, these small changes may be neglected, for they affect but a small percentage of the rock.

TABLE IV.

Changes in State of Oxidation of the Iron in Diabase.

	Fe_2O_3 %	FeO %	Ferrous Iron %	Ferric Iron %	Total Iron %	H_2O %
Original Rock	1·51	8·74	6·79	1·06	7·85	0·61
Original Rock dried at 105°	1·52	8·79	6·83	1·07	7·89	----
Glass, heated to 1346° June, 1912	4·54	6·08	4·73	3·18	7·91	----
Recrystallized block after volume determinations under tin. (From glass of June, 1912)	2·90	7·59	5·90	2·03	7·93	----

The volumes of the rock and its glass at room temperature are given in Table V, in comparison with similar constants determined by Barus for his sample of diabase (see p. 5).

The experimental data are plotted in fig. 9. For the sake of clearness the curves of rising and of falling temperature are plotted separately. No satisfactory measurements were obtained on the second block below 900°, as internal cracking in the glass block caused its volume to appear considerably too large until these cracks were opened by the shrinkage during crystallization.

It will be seen from the curves that the glass expands slightly up to about 900°, when a sudden shrinkage takes place. This is due to the crystallization of the glass, which is of

TABLE V.

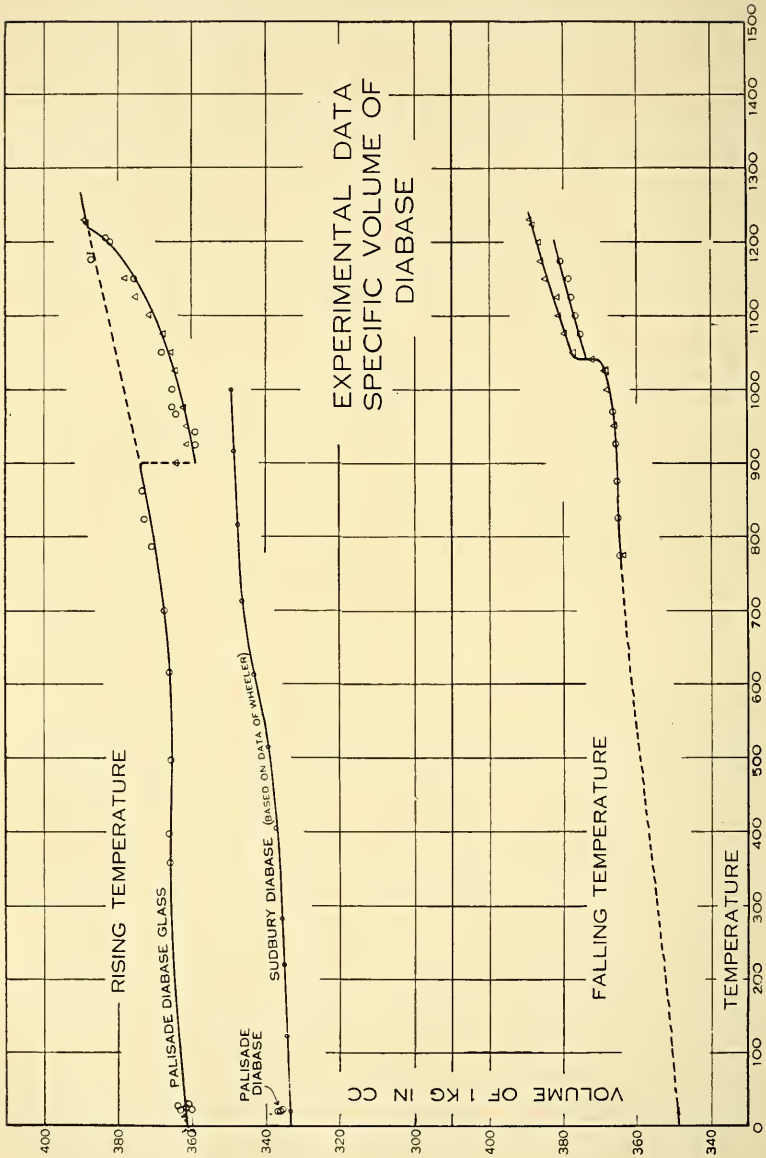
Kilogram-volumes of diabase and diabase-glass.

	Date	Temp.	Wt. specimen	Dens.	Kilo-vol.
Diabase	10 June 1912	22·7	90·017	2·982	335·4
	11 Mar. 1913	19·45	104·553	2·968	336·9
	12 " "	21·3	40·516	2·974	336·3
Mean				2·975	336·2
Diabase-glass	10 June, 1912	22·5	2·1807	2·778	360·0
	" " "	22·8	6·6241	2·752	363·4
	22 June, 1912	24·5	128 05	2·767	361·4
	24 " "	27·8	80·34	2·770	361·0
	11 Sept., 1912	28·2	85·802	2·747	364·0
Mean				2·763	362·0
Diabase (Barus)	1891	25	22·895	3·016	331·6
		21	45·365	3·018	331·3
		21	54·721	3·014	331·8
		21	69·494	3·024	330·7
Mean				3·018	331·3
Diabase-glass (Barus)	1891	21	60·933	2·702	370·1
		19	33·766	2·745	364·3
		19	29·978	2·705	369·7
Mean				2·717	368·0

course nothing more than an undercooled liquid which has failed to crystallize during rapid cooling, but finds a second opportunity to do so with the increased mobility accompanying slow reheating. The heat given off during crystallization, spreading through the graphite float-crucible into the surrounding molten metal, was sufficient to cause a sudden rise of 15° in the temperature indicated by the thermoelement.

The volume to which the block shrinks is not its true crystalline volume. Not only is there insufficient time for close adjustment of the crystals to one another, but the same forces of differential expansion that operate to shatter a complex solid rock operate here to leave the crystalline aggregate in a rather porous condition, with innumerable cracks of appreciable aggregate volume between the fine crystals. The contraction of the glass block on crystallization makes it certain, however, that the crystalline rock has a smaller volume than the glass at this temperature. If there had been no apparent volume change, or if the volume had appeared to increase, the question of the true relation between glass and crystal would have been left in doubt.

Fig. 9.


EXPERIMENTAL DATA
SPECIFIC VOLUME OF
DIABASE
RISING TEMPERATURE
FALLING TEMPERATURE
PALISADE DIABASE GLASS
SUDBURY DIABASE (BASED ON DATA OF WHEELER)
PALISADE DIABASE
VOLUME OF 1 KG IN CC
TEMPERATURE
400
380
360
340
320
300
400
380
360
340
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500

Above the rather accidental temperature at which the glass crystallizes, the crystal aggregate again begins to melt. The melting does not occur at a single temperature, but is spread over a range of temperature, in accord with the fact that this is a complex system of eight or more components. The remelting begins at about 1150° and is practically complete somewhat below 1300°. The rock flows readily at a temperature of 1225°, at which temperature all is fused excepting about a third of the feldspar. A little feldspar still remains undissolved at 1250°, but only traces remain at 1300.°*

A considerable source of uncertainty begins to be apparent at 1100°, which increases as the temperature rises. The reducing action of graphite upon the iron oxides present causes the formation of carbon monoxide between the graphite crucible and the molten rock. The carbon monoxide escapes through the porous graphite, but being constantly renewed, it tends to make the volume of the liquid diabase appear slightly too great. We have found no other material than graphite which can be used in this form of apparatus, so that this gas-producing reaction is a serious limitation upon the method when applied to iron-bearing silicates. Calcium and magnesium silicates seem to be acted upon by graphite very little or not at all at these temperatures.

On the cooling curves a sudden contraction was again observed just below 1050°, caused by the crystallization of the liquid diabase. The resulting volume was approximately that attained when the block of glass crystallized with rising temperature. Below this temperature the contraction was normal as far as it was observed. At room temperature after the measurements the blocks were found to be fine-grained, strong, and very tough. They appeared free from bubbles or vacuoles, except at the surface. Examination under the microscope showed less than 5 per cent of glass present. The blocks were seen to consist of clear feldspar crystals of variable index, the majority corresponding to a basic labradorite; also masses of dark brown feathery crystals too fine to be identified. At 20° the gross kilogram-volume of the blocks was 349·6 and 348·4, mean 349·0; this is 3·8 per cent greater than the volume of the original rock, while the volume of the clear glass was 7·7 per cent greater than that of the rock.

Barus' curves.—The foregoing considerations plainly show what must have occurred in the experiments of Barus (see page 5). Although by rapid cooling in the open air he obtained in his preliminary tests a clear diabase glass, in his fusion tube there was time for the liquid to crystallize at

* For details of fusion tests, see Sosman and Merwin, J.Wash. Acad. Sci., iii, 389–395, 1913.

some point during the cooling; hence the sharp break in his curves. With rising temperature the crystal aggregate then fused at a higher temperature than that to which it had undercooled before crystallizing.

That this conclusion offers the true explanation of Barus' observations is, fortunately, susceptible of direct proof. The original platinum tube and its charge of diabase, just as it was left when the experiments of Barus were interrupted, came into the possession of this laboratory some years ago and was examined. The surface of the melt did indeed appear glassy, but when broken out of the tube and examined under the microscope the diabase charge was found to be about three-fourths crystalline. Occasional small vacuoles were scattered through the mass, due either to bubbles which had never escaped from the glass, or to contraction after the surface had become too stiff to yield.

Since the data of Barus were calculated and stated in terms of the final volume of the rock at room temperature, it became possible to recalculate his volumes, approximately, on the basis of the volume of the rock obtained from the tube. A number of the largest fragments, weighing 35 grams in all, were selected and their total volume determined under mercury. This gives us the nearest possible approximation to Barus' basic volume, since the mercury does not fill the small cracks or vacuoles. The kilogram-volume was found to be 356, as compared with 349·0 for our own recrystallized diabase.

It was necessary also to revise the temperatures in Barus' original publication. Assuming that these temperatures were calculated in terms of the scale published* at about the same time as his bulletin on rock expansion, we have revised the figures to correspond with the high temperature scale in present use.† The recalculated data of Barus' last three series (the first two being stated by him to be much less reliable) are plotted in fig. 10.

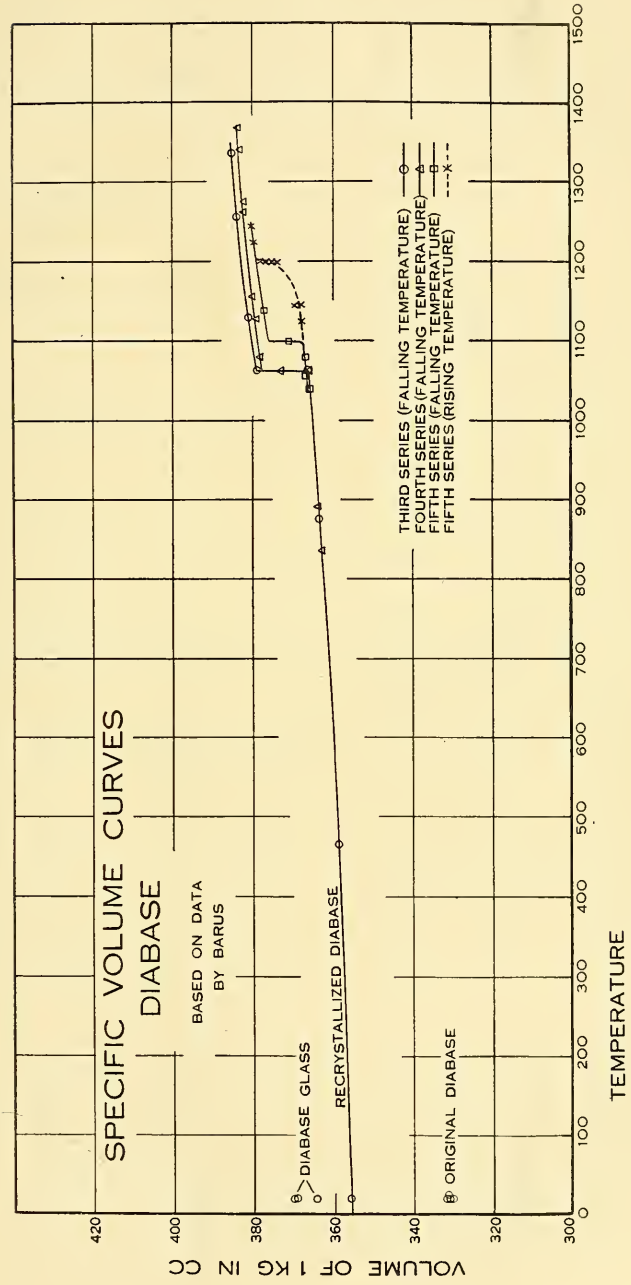
It is plain from these curves that precisely the same phenomena occurred in his diabase as in ours. The liquid cooled to a temperature below that at which crystals would have separated under equilibrium conditions, and then crystallized suddenly with contraction in volume. With rising temperature, fusion began at a temperature above that to which the glass had undercooled before crystallizing. The progressive lowering of the curves is due either to gas bubbles which had not yet escaped from the liquid, or more probably to the sagging of the platinum tube, causing an apparent contraction in total volume.‡

* "Die physikalische Behandlung und die Messung hoher Temperaturen." Leipzig, 1892.

† Day and Sosman, Carnegie Publication 157, 1911.

‡ Barus, Bull. ciii, p. 36.

FIG. 10.


SPECIFIC VOLUME CURVES
DIABASE
BASED ON DATA BY BARUS
DIABASE GLASS
RECRYSTALLIZED DIABASE
ORIGINAL DIABASE
THIRD SERIES (FALLING TEMPERATURE)
FOURTH SERIES (FALLING TEMPERATURE)
FIFTH SERIES (FALLING TEMPERATURE)
FIFTH SERIES (RISING TEMPERATURE)
VOLUME OF 1 KG IN CC
TEMPERATURE
420
400
380
360
340
320
300
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500

Relative volumes of solid and liquid diabase.—The volume of the molten diabase at 1250°, from both of our curves of rising temperature and from our second curve of falling temperature, is 390. The first curve of falling temperature points to a somewhat lower value, which is probably due to incomplete fusion of the feldspar. After the recrystallization with falling temperature the two curves coincide.

Our value 390 for the volume at 1250° is undoubtedly high, since at this temperature carbon monoxide is forming slowly and escaping at the sides of the fused block (see p. 29). The amount of the error can be roughly estimated, from the small depressions left around the edges of the recrystallized block, at about one per cent.

The value obtained from Barus' curves is 383 at 1250°. The net effect of the errors of his method is probably to give too low a value. The figure of 383 which we have obtained from his data is in fact 1·8 per cent lower than our maximum of 390. The most probable value for the volume of a kilogram of liquid diabase at 1250° is therefore about 386.

In the absence of data on the volume at high temperatures of each of the constituent minerals of crystalline diabase, its true volume near its fusion temperature can not be directly measured, on account of the shattering caused by unequal expansion of different minerals and by the escape of gases (see p. 23). It will be necessary, therefore, to resort to a certain amount of extrapolation in order to obtain a value for the volume of the crystalline rock.

In fig. 9 is plotted the volume of Sudbury diabase up to 1000°, calculated from the expansion data of Wheeler* and based on a specific gravity of 2·998 (volume 333·6).† The rock is described as a typical fresh olivine diabase, massive, and possessing a typical ophitic or diabase structure.‡ Its specific volume is only a little less than that of the Palisade diabase.

The curve shows the expansion on the initial heating. The permanent volume increase after this first heating amounts to 2·1 per cent. Extrapolation of the part of the curve below 400° gives a value for the volume of the rock at 1250° of 344. Extrapolation of the portion from 700° to 1000° gives 351. Extrapolation of the curve of falling temperature (1000° to 20°, not shown in fig. 9) also gives 351. The latter value must be regarded as the maximum, representing the expansion of a rock already shattered and permanently expanded. The lower value of 344 is probably nearer the true volume; it corresponds to a mean coefficient of dilatation from 0° of $25{\cdot}2 \times 10^{-6}$. In

* Trans. Roy. Soc. Canada, iv, 19–44, 1910.

† F. D. Adams, private communication, 1913.

‡ Adams and Coker, Carnegie Institution, Pub. No. 46, p. 57.

good agreement with this is the coefficient of $25{\cdot}5 \times 10^{-6}$ for the contraction of the expanded rock from 1000° to 0°.

Comparing the volume of the crystalline rock with that of the glass, and taking the volume of the glass as the basis of comparison, we find that the difference of 7·1 per cent at 0° has increased to a value between 9·1 per cent as a minimum and 10·9 per cent as a maximum, the true value being much nearer to 10·9 than 9·1.

9. *Shale and Sandstone.*

One series of measurements was made on a specimen of the shale which underlies the Palisade diabase at Granton. The block weighed 68·35 grams after drying four hours at 106°. Measurements were made with tin as the immersion liquid. The volume curve showed the characteristic break at 575° due to the inversion of the quartz which was present in the rock (see curves for granite, figs. 7 and 8). At 675° considerable quantities of gas began to come off, interfering with the volume measurements, and the gas evolution continued up to 1090°. The rock was held between 1090° and 1113° for 80 minutes; at the end of this time its volume had increased to 563, an expansion of 46 per cent. This was found to be due to the formation of a spongy mass through the entrapping of innumerable bubbles within the partly fused rock. Subsequent microscopic examination of the original shale showed the presence of datolite in the interstitial spaces: this accounts in large part for the behavior of the shale on heating. Datolite was also found in the arkose sandstone. Its presence renders these rocks unsuitable for volume measurements to a high temperature.

Measurements were also attempted on natural microcline, and a satisfactory curve was obtained as far as 600°. At higher temperatures the gas evolution again proved our undoing, causing shattering of the mineral in the solid state and yielding a bubbly glass at the melting point, the liquid being too viscous to allow the bubbles to escape.

10. *Geological Applications.*

Quartz and granite.—The volume change in quartz between 0° and 500° is 2·8 per cent, and between 500° and 575° it is 2·4 per cent, of the volume at 0°. In other words, the increase during the last 75° before the transition point from low to high temperature quartz is nearly as great as the increase during the preceding 500°. A volume change as rapid as this must be of considerable significance in the crystallization of the siliceous rocks. As Fenner has pointed out in his recent

work on the silica minerals,* the fact that quartz in pegmatites is frequently found to have crystallized in the neighborhood of 575° may be connected with the opening of fissures in the cooling granitic rock by the sudden volume change taking place in quartz which has already crystallized.

But the significance of this point is not alone in the suddenness or the amount of the volume change in the mineral, but also in the small heat effect which accompanies it. The crystallization of a magma may be accompanied by a considerable volume change, yet the amount of latent heat given out during crystallization might delay its progress to such an extent that the volume change of the mass as a whole would proceed relatively slowly. But the amount of heat accompanying the quartz inversion is too small to seriously affect the rate of cooling of the rock, so that the volume contraction, at this temperature (575°), of a rock containing much quartz would be sudden and considerable.

In his papers on "The mechanics of igneous intrusion,"† Daly suggests that an important cause for the cracking off of blocks of rock in contact with a liquid intrusive mass is to be found in the unequal expansion due to sudden heating. The experiments on quartz and granite in the preceding pages emphasize rather the much greater importance which must be ascribed to the sudden volume change accompanying the transition of quartz at 575°, or to other similar transitions. Their effect in shattering the rock is much greater than the effect of ordinary thermal expansion even in a region of steep temperature gradient. The result, however, would not be the breaking off of large blocks which, according to Daly's "stoping hypothesis," must then sink in order to be assimilated at greater depths, but rather the formation of a shattered porous material which would be in the best possible condition for immediate assimilation *in situ*.

Moreover, the capillary penetrating power of liquid diabase into a porous mass of this character is very considerable. Diabase melted in a crucible of alundum (granular fused alumina) came through the sides of the crucible, and rose by capillarity in the walls like water in filter paper. We have even found numerous tiny drops of diopside on the outside walls of the inverted graphite float-crucible of the apparatus of fig. 1, the liquid silicate apparently having been forced through the fine pores of the graphite by the small pressure of the surrounding molten tin.

Daly has assembled in his paper on "the secondary origin

* C. N. Fenner, this Journal, xxxvi, 379, 1913.

† R. A. Daly, this Journal, xv, 269–298, 1903; xvi, 107–126, 1903; xxvi, 17–50, 1908.

of certain granites "* a large number of instances in which it is believed that a basic intrusive has assimilated acid rocks along its contacts. The shattering of a siliceous rock by the quartz inversion, and the penetrating power of liquid diabase and diopside, which we have noted above, lend additional plausibility to Daly's view of the phenomena.

Diabase and sandstone.—Returning now to the question of the "floated" sandstone and shale slabs described by Lewis (see p. 25) our experimental data again find application. A

FIG. 11.

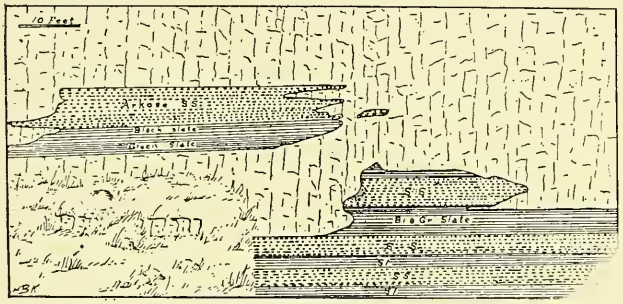


FIG. 11. Diagrammatic sketch of the contact of the trap and underlying shale at the base of the cliff at Linwood, on the Palisades. (After Kümmel.)

fragment of pure quartzite without pore spaces would have at 1150° a kilogram-volume of about 395, supposing it not to have inverted to tridymite or cristobalite. Diabase glass at 1150° would have a volume of 384. The quartzite would be, therefore, 2·9 per cent lighter than the fused diabase, and would float up in it, if free to move.

The arkosic sandstone which forms the majority of the inclusions in the Palisade diabase consists chiefly of quartz and orthoclase. Extrapolation of our curve for orthoclase (see p. 33) would give it a volume at 1150° of about 404. The average volume of the arkose (about one-third quartz and two-thirds feldspar), would therefore be 400 at 1150°, or 4·2 per cent lighter than the liquid diabase. Loose slabs of the arkose would therefore tend to float up into the diabase sheet.

Such floating due to normal gravitative adjustment would seem to offer the simplest explanation of the frequent occurrence of slabs of the underlying rock found in various positions in the Palisade sheet. A good example is seen in the sketch

*R. A. Daly, this Journal, xx, 185–216, 1905.

by Kümmel (fig. 11), made at the base of the Palisades above Jersey City. Fig. 12 is from a photograph at the Belle Mountain quarry mentioned by Lewis.* A slab of variable thickness here stands nearly vertical in the diabase sheet, and appears conspicuously at the center of the picture. The

Fig. 12.

Fig. 12. Slab of arkosic sandstone in the diabase sheet at the Workhouse Quarry in Belle Mt., east bank of the Delaware River, above Moore, New Jersey. (Photograph by R. B. Sosman, 24 July, 1913.)

* Loc. cit., p. 135 (6).

quarrying operations of the past several years have been following this slab back through the diabase.

Lewis' explanation of these occurrences is found in the following quotation:* "The first step in such a process is seen in Plate XXII, fig. 1, where a thin sheet of the diabase has followed a bedding-plane about a foot below the base of the main sill. If any portion of the intervening sedimentary bed had broken or parted along a joint-plane and the edge had tilted up somewhat against the flow of the intruding magma, it would have been raised by the current to a more steeply inclined or even vertical position." But this can hardly be a complete explanation, as no force is suggested which could start the slab tilting up against the flow. The intruding diabase can not be compared to a stream flowing freely over a flat, irregular bed, and lifting up blocks by its own momentum. On the contrary, we must assume that it flowed relatively slowly, under considerable pressure from overlying rock strata. Under these circumstances a thin sheet of liquid diabase, branching off from the main mass and following a bedding plane, would indeed exert a lifting pressure on the under surface of the slab of sandstone; but this pressure would exceed that on the upper surface by only a small amount, namely, an amount depending on the difference in density between the sandstone and the diabase. In other words, the sandstone would be lifted by the same force that lifts a piece of wood which is immersed in water.

It is possible that the moving current of diabase might carry the slab along after flotation had lifted it from the floor. But this assumption is not necessary in order to explain the frequent vertical position of the slabs, since this is the position which any flat object tends to assume when floating up through a liquid.

Temperature of intrusion of the diabase.—A comparison of the fusing temperatures of the arkose and the diabase yields the interesting fact that the arkose fuses at a lower temperature than the diabase. Nevertheless, in the inclusions actually found there is no sign of fusion. This discrepancy led us to make a more thorough investigation, with the assistance of Dr. Merwin, of the fusion temperatures of the two rocks. This was done by means of quenching tests and microscopic examination, of which the results have already been published elsewhere.† Briefly summarized, the conclusions were as follows:

(1) The "basaltic" facies of the Palisade diabase begins to fuse at about 1150°, and enough of it is fused at 1225° to permit the rock to flow readily. (2) The arkose now found in

* Loc. cit, p, 134, 1907.

† R. B. Sosman and H. E. Merwin, J. Wash. Acad. Sci., iii, 389–395, 1913.

the diabase in the form of inclusions is more than half fused at 1150°, but shows no fusion at 1025°. (3) The inclusions as actually found show no indication of fusion or flow. *As indicated by their present properties* under atmospheric pressure, there is therefore a gap of at least 100° between the maximum temperature to which the arkose inclusions could have been subjected, and the minimum temperature at which the diabase will flow. The most probable agent which possesses the power to bridge this gap is the water content of the diabase magma, of which the surrounding rocks show abundant evidence. At the time of the intrusion water was undoubtedly present and served to lower considerably the fusion temperature of the diabase.

It is evident, then, that we are by no means at the end of the geological problem of the relative volumes of crystalline and molten rocks when we have determined their volume under the conditions of pressure and composition in which we now find them at the surface of the earth. The effect of the volatile components, now present only in traces or perhaps entirely absent from the rock, is still to be taken into account. The effect of dissolved water, for instance, on the volume of liquid diabase as given in the preceding pages, is unknown, although an amount sufficient to produce large changes in melting temperature and viscosity will probably be found to produce relatively small changes in volume. Data such as we have presented are absolutely necessary, however, as a basis upon which to build further knowledge of the volatile components, when methods are worked out for including them.

Summary.

After reviewing existing and rather conflicting data on the change in volume on fusion of various rocks, we have described apparatus by which the volume of metals and of solid and liquid silicates can be determined from 250° to 1600°. The sensitiveness of the method is from 0·03 to 0·2 per cent. The accuracy varies with the metal used, the temperature, and the size of the sample, but is usually between 0·2 and 0·5 per cent.

The fundamental constant is the expansion coefficient of artificial graphite, which is given by the formula $10^6 = 0{\cdot}55 + 0{\cdot}0016\,t$. In Table I (p. 14) are given the volumes of tin, lead, and the tin-lead eutectic in the liquid state at various temperatures.

Volume measurements on quartz up to 1600° show a dilatation which increases rapidly as the inversion point of 575° is approached. Above this temperature quartz contracts slightly. At about 1300° there begins a second and (under these

conditions) irreversible dilatation due to the formation of cristobalite.

Granite has a curve of similar form. Above 575° granite undergoes a permanent dilatation caused by the shattering effect due to the different expansion coefficients of its minerals and to the escape of gases.

The volume of diabase glass was determined up to 1250° and compared with Barus' well-known values. A simple explanation of some of the conflicting features of his observations has been found.

Diabase expands considerably in liquefying. The difference in volume between crystalline and glassy (liquid) diabase at 1150°, at which temperature the crystalline rock begins to fuse, is about 10·9 per cent of the volume of the glass, or 12 per cent of the volume of the crystalline rock at that temperature. At 0° this difference is 7·7 per cent of the volume of the rock.

A consideration of the comparative specific volumes of quartzite or feldspathic sandstone on the one hand, and liquid diabase at the same temperature on the other hand, shows that the diabase is denser, and slabs or fragments of the sandstones would therefore tend to float in it. This seems the best explanation of the peculiar sandstone inclusions in the Palisade diabase described by Lewis.

Volatile components, now absent from the diabase as we find it, seem to have greatly modified its temperature of intrusion, and make it impossible at present to solve completely the problem of relative volumes under the original conditions of intrusion. The foregoing measurements, however, furnish a necessary basis, on which the variation due to volatile components can be established.

Natural rocks are unsatisfactory for measurements of this kind for three reasons: (1) from the chemical standpoint they are very complex systems, between whose properties it is difficult to find a simple relation: (2) the unequal expansion of the various minerals fractures the rock so that it is impossible to determine its true volume change over any considerable range of temperature; (3) the natural rocks give off considerable quantities of gas. The best plan for future work, therefore, would seem to be to determine the volumes at high temperatures of simple silicates, prepared in the laboratory and free from gases. Their other properties can then be controlled, and it will become possible to find definite relationships between composition and dilatation. Such measurements have been begun, and will be reported on at a later date.

Geophysical Laboratory, October, 1913.

ART. II.—*Notes on a new occurrence of Pisanite and Arsenopyrite, and some large Staurolite Crystals from the Ducktown District, Tennessee;* by FRANK ROBERTSON VAN HORN.

Introduction.

DURING the month of June, 1912, the writer spent about three weeks with a class of Case mining students in the vicinity of Ducktown, Tennessee. While visiting an abandoned open cut of the Ducktown Copper, Sulphur, and Iron Company at Isabella, considerable amounts of a sulphate deposit of secondary origin were observed. These minerals were colored green in some places, but blue was the prevailing color for most of the formation. It was at first thought that the green mineral was melanterite ($FeSO_4+7H_2O$), and that the blue substance was chalcanthite ($CuSO_4+5H_2O$). However, the green deposit was rubbed with a knife blade which was immediately colored by the precipitation of copper, which proved that the mineral could not be melanterite. Subsequent tests and analyses showed that neither melanterite or chalcanthite were present, but that both the green and blue minerals were pisanite with varying proportions of iron and copper. Since pisanite has never been reported from the region, as far as the author is aware, the new occurrence has been thought worthy of record.

Pisanite.

As has been previously stated, the mineral was found in two varieties, green and blue, on the walls of an abandoned open cut at Isabella, Tenn. This locality is situated about one and one-half miles east-southeast of Ducktown. A view of the open cut workings is shown in fig. 1, in which the light-colored deposit along the right hand wall consists of pisanite. The blue variety is found in greater abundance than the green mineral. Both substances are transparent and are found as crusts, botryoidal coatings, and stalactites on the walls of the cut, which consist chiefly of pyrite with some pyrrhotite and chalcopyrite. Fig. 2 is a nearer view of the occurrence shown in fig. 1. In fig. 2 some small stalactites are visible, and the botryoidal appearance can also be noticed. Limonite has precipitated in large amounts from the water to be seen in the lower right hand corner of the picture, and the water is quite highly charged with copper. In some places the deposits are more or less hollow, and the cavities show distinct crystals. Many specimens were collected, and no change was noticed in their appearance until after six months when the surface of practically all pieces became white and opaque.

Fig. 1.

Fig. 1. Open cut workings at Isabella, Tennessee, showing light-colored deposit of Pisanite above water in the lower right hand corner.

Fig. 2.

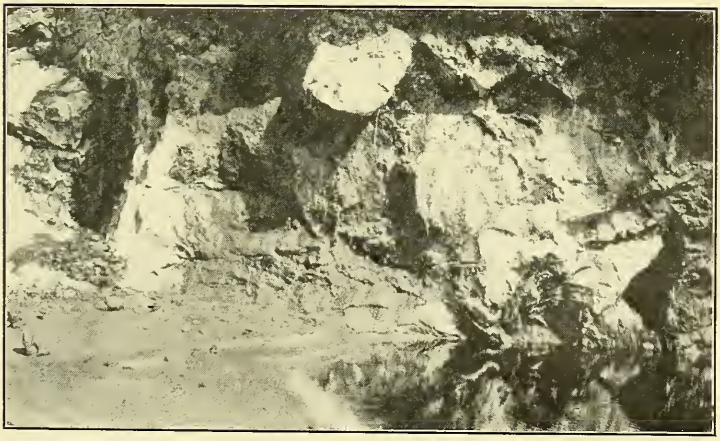


Fig. 2. Nearer view of Pisanite deposits showing stalactitic and botryoidal formations.

Chemical Composition.—Some five months after the mineral was collected, transparent specimens of both blue and green varieties were submitted for analysis to Dr. W. R. Veazey, Assistant Professor of Chemistry at Case School of Applied Science, and the writer is under great obligations to Professor Veazey for the analyses. Although the specimens had been in a dry place so long after being collected, nevertheless some moisture was noticeable when the mineral was broken. It was, however, not deemed advisable to dry the specimens by artificial means on account of the possible oxidation of the iron, and also for fear of driving off some of the water of crystallization which has been stated by Schaller* probably to take place between 100°–110° C.

Blue Pisanite.—Below is given under (1) the analysis of the blue pisanite from Isabella, Tenn. Under (2) and (3) are to be found analyses of pisanite by Dr. Schaller† from the Alma mine, Leona Heights, Calif. Under (4) is to be seen the original analysis of the pisanite from Turkey by Pisani.‡

	(1)	(2)	(3)	(4)
SO_3	27·87	29·28	29·25	29·90
FeO	17·18	16·47	5·46	10·98
CuO	8·50	9·22	17·95	15·56
MgO	0·47	----	2·82	----
H_2O	46·47	45·74	45·21	43·56
	100·49	100·61	100·69	100·00

An inspection of the various analyses shows a very great similarity between analyses 1 and 2. The water is evidently too high in 1, and was probably due to a small amount of moisture in addition to the water of crystallization. The water in 4, on the other hand, is certainly too low, and was probably determined by Pisani only by difference as the analysis totals 100 per cent, and this kind of analysis practically always totals higher than 100. One interesting feature of the Isabella mineral is the small percentage of magnesia. This indicates the presence of a small amount of the very rare cupromagnesite§ molecule, $(Cu,Mg)SO_4+7H_2O$, which is isomorphous with melanterite.

Analyses of mine waters‖ from the region show the presence

* Minerals from Leona Heights, Alameda Co., California, by W. T. Schaller, Bull. Univ. of California, vol. iii, pp. 204–206, 1903.

† Op. cit., pp. 206–207

‡ Comptes Rendus, xlviii, 807, 1859.

§ System of Mineralogy, Dana, p. 944.

‖ Preliminary Report on the Mineral Deposits of Ducktown, Tennessee, by W. H. Emmons and F. B. Laney, Bull. 470, U. S. Geol. Survey, p. 172, 1910.

of magnesium in small quantities. In analysis 3 by Schaller much more magnesia is found than in the Isabella mineral. In order to calculate the formula from the analysis, since the magnesia replaces ferrous iron, it has been recalculated as that substance with the following results:

	Recalculated analysis	Combining weights	Molecular ratio
SO_3	27·87	·348	3·25
(FeO,MgO)	18·02	·251	2·34
CuO	8·50	·107	1·00
HO	46·47	2·585	24·15
	100·86		

The molecular ratios obtained from analysis 2 by Schaller are $2FeO.CuO.3SO_3+21HO$, and the ratios of the blue pisanite from Isabella conform very closely to this formula, with the exception of the water, which is 3 molecules too high and must be ascribed to moisture in the original substance. The theoretical percentage required by the formula $2FeO.CuO.3SO_3+21H_2O$ would be as follows:

SO_3	28·53
FeO	17·08
CuO	9·45
H_2O	44·94
	100·00

Green Pisanite.—The results of the analysis of the green mineral were obtained by Dr. Veazey as follows:

SO_3	28·72
FeO	21·45
CuO	3·83
MgO	0·39
H_2O	45·58
	99·97

When this analysis is compared with that of the blue variety, the most noticeable differences are the increase of iron and decrease of copper which was to be expected from the green color. In other words, the green mineral is a pisanite nearer melanterite, whereas the blue substance is a pisanite approaching the rare mineral boothite ($CuSO_4+7H_2O$), which

Schaller* has shown to be isomorphous with melanterite forming pisanite. Of incidental interest is the fact that the formation of both green and blue pisanite have caused a secondary enrichment of the copper by oxidation, since the sulphide ores of the district contain an amount which averages slightly under two per cent. The small percentage of magnesia is seen to be fairly constant in both varieties. When we calculate this MgO as FeO, the analysis becomes as follows:

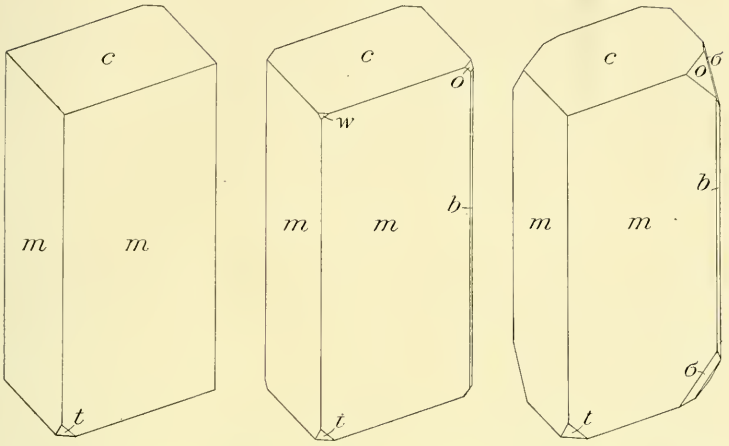
	Recalculated analysis	Combining weights	Molecular ratio
SO_3	28·72	·359	7·48
(FeO,MgO)	22·14	·308	6·42
CuO	3·83	·048	1·00
H_2O	45·58	2·530	52·71
	100·27		

About the nearest logical formula for the green pisanite would seem to be seven times that of the melanterite formula, or $6FeO.CuO.7SO_3+49H_2O$. In this analysis it would seem that the water is even larger than in the blue mineral although the same is nearly a per cent lower. In all published analyses of the pisanite the size of the molecule seems to vary, although all occur in multiples which adhere closely to the general formula $(RSO_4+7H_2O)_x$. It is very clear from the analyses of the Isabella varieties as well as those from other localities that iron and copper have no fixed relation to each other, but that they may replace each other in any proportion.

Crystallography.—Although the analyses of the mineral showed quite conclusively that the substance was pisanite, and not a mechanical mixture of melanterite and chalcanthite, as might be claimed, nevertheless, it was thought advisable to see if any measurable crystals could be obtained. The writer, after breaking up several specimens of the blue pisanite, was able to find some cavities lined with well-defined crystals. Because of his previous experience with pisanite from California, Dr. W. T. Schaller† of the U. S. Geol. Survey, Washington, D. C., was asked to see if he could obtain any crystallographic results on the material selected. I wish to express my thanks to Dr. Schaller for his data which follow, and also especially for his drawings, figs. 3, 4, and 5. Dr. Schaller has observed seven forms which are fairly common for pisanite with the exception of σ ($\bar{1}21$), which was first discovered by him on the mineral from the Alma mine, Leona Heights, California. Dr. Schaller's results follow:

* Op. cit., p. 207. † Op. cit., pp. 199–207.

Fig. 3. Fig. 4. Fig. 5.



Figs. 3, 4, and 5, Pisanite crystals from Isabella, Tennessee, drawn by Dr. W. T. Schaller.

Forms determined:

b (010), very narrow, figs. 4 and 5.
c (001), large figs. 3, 4, 5. Cleavage.
m (110), large, dominant form, figs. 3, 4, 5.
o (011), small, figs. 4 and 5.
w (103), minute, fig. 4.
t ($\bar{1}01$), minute but larger than *w* figs. 3, 4, and 5.
σ ($\bar{1}21$), minute, fig. 5.

(Average) Measured and Calculated angles:

	Measured		Calculated	
	ϕ	ρ	ϕ	ρ
b (010)	0° 17′	90° 00′	0° 00′	90° 00′
c (001)	89 23	15 54	90 00	15 11
m (110)	41 34	90 00	41 36	90 00
o (011)	9 35	57 19	10 07	57 04
w (103)	88 27	36 29	90 00	35 48
t (101)	89 21	47 06	90 00	47 09
σ (121)	18 33	72 06	19 32	72 46

The results of the crystallographic observations given above prove conclusively that the blue mineral is pisanite and not a mechanical mixture of melanterite and chalcanthite as some might claim.

Arsenopyrite.

One of my students, Mr. P. A. Fruehauf, found in the schistose walls of the ore body of the London mine, Ducktown district, two crystals which he brought to the writer for deter-

mination. One crystal measured 5×7^{mm}, and the other was 9×14^{mm}. The general habit of both resembled that of danaite or glaucodot rather than that of most arsenopyrite. Blowpipe tests revealed the presence of iron, arsenic and sulphur with just a trace of cobalt, so that the mineral is undoubtedly arsenopyrite rather than danaite. The specific gravity is 6·05. Mr. Walter F. Hunt, Instructor in Mineralogy at the University of Michigan, very kindly offered to measure and draw the crystals, and I wish to thank him for his assistance. The following forms were determined m (110), q (011), n (012).

Fig. 6.

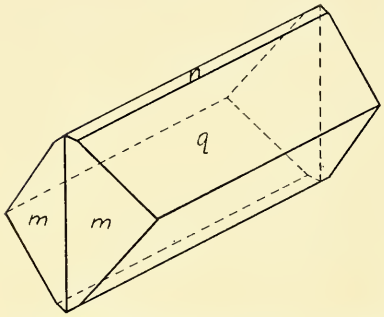


Fig. 6. Arsenopyrite from London mine, Ducktown, Tennessee. Drawn by Mr. W. F. Hunt.

Angles measured.

$m : m'$	68° 39′
$q : q'$	100° 1′
$n : n'$	61° 42′

The drawing is shown in fig. 6 where it is readily seen that the largest face is the brachydome q (011), and that the brachydome n(012) is very small. The habit is rather unusual for arsenopyrite, and as far as the writer can learn, that mineral has also never been previously reported from the Ducktown region.

Staurolite.

This mineral has long been known from the general district of eastern Tennessee, western North Carolina, and northern Georgia. Emmons and Laney* have carefully traced certain staurolite layers in the schists of the Ducktown region on account of their probable relation to former sedimentary rocks which had presumably been replaced, with the consequent formation of the iron and copper sulphide deposits. It is the present purpose of the writer only to call attention to a fact of mineralogical interest which has apparently been overlooked, namely the extremely large size of some of the staurolite crystals. The largest were found in Mill Creek Valley not far from the Copperhill smelter of the Tennessee Copper Company. The locality was visited three times, each with a different section of students, and the writer is not sure but that the students may have collected larger crystals than are shown in fig. 7 which are approximately half the size of the natural

* Op. cit., p. 158.

crystals. The only faces observed were *m* (110) and *b* (010). No terminal planes were developed and all faces were rough. The single crystal on the left in fig. 7 measures about 5^{cm} wide, 10^{cm} long, and 4^{cm} thick. The other two are twins after *z* (232). The central crystal is 5^{cm} wide, 8^{cm} long, and 6^{cm} thick. The largest specimen is the twin on the right which is tabular and measures 8^{cm} wide, 9^{cm} long, and 3½^{cm} thick. The writer has

Fig. 7.

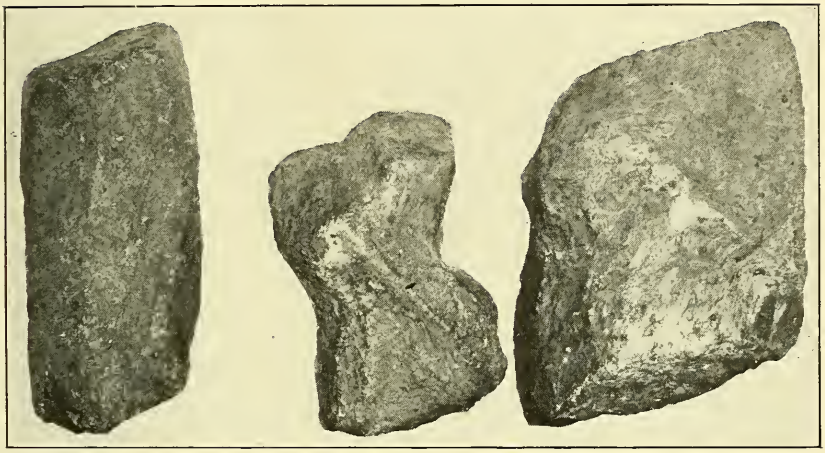


Fig. 7. Large staurolite crystals (one-half natural size) from Copperhill, Tennessee. The one on the left is a single crystal, and the other two are twins after *z* (232).

never seen any staurolites in this country or Europe which approach the size of these crystals. All crystals were either single individuals, or twinned after *z* (232), and none twinned after *x* (032) were found. It may possibly be a matter of interest to know that out of several hundred small staurolite crystals found near Mineral Bluff, Fannin Co., Georgia, only 11 were found twinned after *x* (032). The remainder were about equally divided between single crystals and those twinned after *z* (232). The large staurolites of the Ducktown district are all altered to an irregular aggregate of chlorite, muscovite, and garnet, with a little magnetite. In some places the crystals were evidently formed after the schistose structure of the surrounding rocks was developed.

Geological-Mineralogical Laboratory,
Case School of Applied Science, August, 1913.

Art. III.—*The Diagrammatic Representation of Volcanic Phenomena;* by Frank A. Perret. With Plates I to IV.

As an aid to comprehension in the presentation of a subject the *visual* sense is now appealed to in a constantly increasing degree and a description without illustrations, a report without a drawing, or a lecture without projections has become almost an exception. Exquisitely sensitive to infinitesimal variations of form and of angle, the eye is capable of conveying to the mind, not only the reproduction of a scene, but even the summed-up impression of a series of measurements, or the net results of a laborious analysis, as presented in a diagram or curve. And, in such a case, it is precisely this property of totalizing, so to speak,—of eliminating distracting intervals and showing, almost at a glance, those collected values which must otherwise have been considered one by one—which constitutes the principal advantage of this method, and gives to it the quality of being at once analytic and synthetic. We may see, therefore, the gradual cooling down of a molten mass plotted out in the form of a curve, of which beginning, progression and end are visible and comparable; the details of plant growth analyzed and totalized in a diagram; the composition of rocks exhibited for comparison in a series of geometrical designs. But it would be superfluous to insist further upon the value of the principle—it is a theorem not needing demonstration.

Can a diagrammatic method be devised for presenting the characteristics of volcanic action?

It may be said, first of all, that the process of photographic illustration has already rendered immense service to this branch of science whose phenomena are unfamiliar to the mass of mankind and are of a grandeur and beauty which baffle description. The earlier sketches were often but caricatures, in many instances reducing the average volcanic cone to the apparent dimensions—and almost to the angles—of a church steeple, and it is by photography alone that the reality can be adequately portrayed and thus conserved as a precious document for all time.

But even this process is circumscribed and limited in its practical application, not merely by the frequent elimination of the *sine qua non* by clouds of erupted material but also by reason of the fact that a large proportion of volcanic manifestations are invisible and, finally, because the photographic record is fragmentary and lacking in the above-mentioned element of totality. It is evident, therefore, that a further means

of expression is needed—a method of graphically setting forth all the phenomena in their just proportions and thus to reveal, in a composite figure, the true *character* of the volcanic activity. The complete presentation of any volcanic event will then be of a threefold nature, consisting of the written description, the photographic illustrations and the diagrammatic interpretation of the eruptive characteristics.

Long convinced of this need, the writer has devoted himself to the problem of devising a method which should be simple and thoroughly practical and, at the same time, so comprehensive as to fully attain the scope of the undertaking, and this is believed to have been finally achieved in the form herewith presented.

The Diagram Chart.

This is furnished in the form of a simple postcard which is easily handled, readily carried in the pocket and mailable at lowest rates. One side is spaced for the address and for notes, while the other is devoted to the diagram proper (see Plates I–IV, giving twelve examples, each reduced one-third) which is constructed as follows:

Eight radiants diverge from a center and terminate in a correspondingly divided circle which, with its extensions, forms the *key* of the diagram. The circle divisions are marked to represent the various phenomena, which are here expressed in the most general terms—explosive, effusive, seismic, etc.—and are then developed and extended into subdivisions indicated by letters and numbers.

Each radiant is a line of ten small, blank circles destined to be blackened or filled in progressively from the center outward, according to the value assigned to the phenomena which it represents. Tie lines are then to be drawn between the radiants intercepting these at the marked extremities, thus enclosing a space and constituting a *figure*, to the form and angles of which the eye is peculiarly sensitive.

This construction of the radiants has been adopted, not only as forming a convenient decimal scale of values, but because it is easier to blacken a small circle than to draw a straight line, and also for the reason that a more salient appearance is thus given to the radiant proper—which indicates the real value assigned to the characteristic—than to the rest of the figure as formed by the intercepts.

The subdivision is to be indicated in the diagram by its letter and number, and in the case of there being more than one—and of lesser value—its circle may be left blank, thus contrasting with the others and marking the value of that particular detail, all of which is clearly shown in the examples accompanying this article.

Before taking up the consideration of the various phenomena it may be well to realize the scope and limitations of the method. The volcanic forces and manifestations not being generally measurable in exact terms, it is obvious that the diagram will not be of mathematical precision. It is not intended to indicate, for example, the explosive pressure in any given outbreak nor to compare this rigorously with that of another volcano, but the object is rather to present the various phenomena of an eruptive phase in their relative proportions, and thus to reveal its character. The maximum values once adjudicated, it is easy to estimate the others in relation thereto, and this is far simpler than might, at first, be supposed. At Etna, for instance, in 1910, the great stream of lava, issuing at torrent velocity and extending nearly ten kilometers, easily formed the distinguishing characteristic and, constituting as it did, even for this volcano, a very notable outflow, it is indicated on the diagram with the full ten points. At Teneriffe, instead, although the lava-flow constituted the principal external manifestation, its magnitude was mediocre, not merely *per se* but also more in comparison with former outflows in the same general locality, and the value assigned to it on the diagram is seven points.

It will be evident, also, that the difference of a point either way will not, as a rule, materially affect the integrity of the diagram. At Stromboli, 1912, the electrical phenomena are indicated by a radiant of six points. A second observer might have argued against a higher value than five on the ground of the brief duration of the phenomena, while a third might have assigned seven points in order to give prominence to a manifestation extremely rare at this volcano—all would have been agreed, however, as to a characteristic of very notable, but not paramount, importance and thus, in any case, the radiant would have a value conveying this impression.

In the case of certain outbreaks of brief duration—and especially those in which the character of the action does not greatly change during the course of the eruption—a single diagram may be made to represent the entire event. This has here been done with Teneriffe 1909, Stromboli 1907 and 1912, and, somewhat reluctantly, with Etna 1910. But it is evidently preferable that the diagram should show the eruptive conditions at a given time, different phases being represented on separate charts and forming a series of documents revealing the progression of the eruption, and it is here that the beauty and value of this graphic method is most clearly seen. At the great Vesuvian outbreak of 1906 the character of the eruptive phenomena swung through a succession of intermerging but widely differing phases, the more salient of which

are here represented in six diagrams showing the development and progressive variations of that important event.

It may be of interest to note that any volcanologist could, from these diagrams alone, mentally construct and vividly and correctly describe the eruption. This is evidently working in the wrong direction and is not to be recommended, but the fact is mentioned as showing the effectiveness of the method.

Considering now the characteristics constituting the key of the diagram, the reader will at once perceive their emplacement to be that which is most in accord with the nature of the phenomena. Thus, the upwardly diverging radiants represent the explosive phases, the vertical being devoted to volatile and aërial products and phenomena, with the fragmental ejecta adjacent on either side. The lower perpendicular indicates degradation and deformation of the volcanic edifice by the general phenomena of descent. The effusive line is horizontal, on the right, while the left-hand corresponding radiant represents electrical effects, and is adjacent to the ash and detritus which are essential to their development. Seismic phenomena are placed at the lower right, while the so-called solfataric, i. e. fumarolic, phase of activity is represented at the lower left.

Speaking in the most general terms, the right-hand divisions present the more direct products and phenomena, while those at the left are of an accompanying or resultant nature. These will be seen to correspond in some degree—especially as regards the ejectamenta—with certain terms which have been proposed, and in part adopted, for distinguishing the principal classes of phenomena and products, but which, however convenient for general descriptions, either fail in consistency under the test of the diagrammatic method or are inapplicable because of the difficulty of observational classification. They invariably constitute an imperfect and limiting terminology, and are here best avoided.

We shall now examine in detail the various subdivisions of the analytical key, beginning with the "Explosive" phase.

The gases issuing from active lava on its first coming to the surface—and even under other conditions—will frequently burn with the production of true flame, which is sometimes lost to view in the glare of the lava. At Etna in 1910 the flames were ten meters in length, and at Kilauea in 1911 each lava-fountain jet emitted a flash of burning gas.

Apparently a product of this combustion, but possibly also formed without it, the transparent bluish vapor constitutes one of the commonest of volcanic exhalations. It is the bane of the photographer in inter-crateric work, where its transparency deceives the eye and its actinic color veils the photographic image. The white "panache" is a characteristic feature of

modern activity, being divided, when the emission is strongly intermittent, into puffs, rings, vortices, etc.

Stronger explosions form waves of aërial concussion, often destructive, as at Stromboli in 1907, when most of the windows on the island were shattered to fragments. At Krakatoa the aërial concussion was of enormous power. When these waves result from explosions, which are very sharp and sudden as well as powerful, they may be visible near their source as "flashing arcs," springing upward and outward from the crater.*

Subterranean detonation is frequently so powerful as to be heard at enormous distances. The magnitude of these deep-seated manifestations is sometimes greater than that of the surface eruption, as was the case at Teneriffe in 1909.†

Catastrophic explosion is that of extraordinary violence, generally involving considerable deformation of the volcano itself, and extending its destructive effects to the surrounding regions (Vesuvius 1906, Pelée 1902, Krakatoa 1883, etc.).

The "Fragmental" division, on the right, represents those products issuing most directly from the active lava, commencing with that of the most liquid consistency.

Lava Fountains, with the constant product of their scattering jets—the filamentary lava, or "Pele's hair." Glass foam—the so-called thread-lace scoriæ, or "limu," and the interesting little lava drops—"Pele's tears."‡ Section *b* represents ejecta from a somewhat more viscous quality of lava, the vitreous sand often formed from the surface material in great quantities by the expanding gases, the well-known lapilli and scoriæ and the figured projectiles and bombs. In section *c* we have ejected *pumice* and that marvelous result of rapidly exploding viscous lava which is the *nuée* ardente.

A digression must here be made in order to point out that the diagram is not, and cannot be, concerned with the origin or cause of the phenomena, nor with the chemical nature of the products. For example, explosion may be due to juvenile gases or to those of purely "phreatic" origin, but this is a matter for ulterior investigation and description—the diagram records the physical phenomenon. Similarly, the water of a mud-flow may be volcanic or wholly meteoric, or it may result from the melting of snow by hot volcanic gases—this is matter for the observer's notes. And—more important still—ejected ash may be due to the trituration of "old material," or it may, on the contrary, consist of finely divided magma from the lower parts of the conduit and, therefore, be a direct ejection of co-

* This Journal, xxxiv, 329, October, 1912.
† Volcanological Review, No. 1.
‡ This Journal, xxxv, 611, June, 1913.

eval lava.* But it is often exceedingly difficult to distinguish between the two varieties and, as regards the diagram proper, an emission of ash is to be represented as such, and ulterior information given in writing.

As for the nuée ardente, its complex constitution of exploding lava, avalanche form, and cauliflower ash-cloud development, makes it somewhat difficult of emplacement, but this has here been done on the basis of its fundamental nature, viz., that of a direct, explosive-fragmental product. This rare phenomenon should not be confounded with the hot ash avalanches mentioned below.

A study of the chart will also show that, in some cases, a certain subdivision will not need to be indicated on the diagram, as it will be understood from the other phenomena. For example, in the case of strong ejection of bombs and scoriæ directly from the active lava—especially at a volcano of the liquid lava type—it would be superfluous to indicate the "crater-glow."

Another point requiring explanation, and which some may be disposed to criticise, is the omission of a number of formations resulting from the various activities. Avalanches and mud-flows will form "brèches" and "conglomerates," cones may be erected by fragmental ejecta, etc., but all these involve the time element and are not, strictly speaking, contained within the category of the phenomena and immediate products of eruption, and should not, therefore, be made to encumber the diagram.

We now return to the diagram key, at the left hand "Fragmental" division. The products here are non-luminous, or only partially so, according to the conditions of their ejection and the temperature of the gases, and consist of débris projected in rapid jets or majestically unfolding volutes, or quickly darting spear-head formations. These, in case of a powerful emission, will form the ash "*pino*," from which descend the showers of ash. When the explosive power is sufficient, angular blocks and bowlders are added to the ejected débris. The presence of water, either volcanic or meteoric, may result in the concentration of the air-borne ash into pea-like spheres—the pisolites,—or, if in great quantity, precipitate the ash cloud in veritable showers of mud.

The "Effusive" division begins with inter-crateric flows of lava which, with the ejecta, constitute the usual process of crater filling. Lava lakes also are included in this division,

* See Johnston Lavis: "The Mechanism of Volcanic Action," Geological Magazine, October, 1909, p. 441. See also paper by the present writer in this Journal, xxxiv, 405, November, 1912, written in ignorance of having been anticipated by Dr. Johnston Lavis in this matter of direct ash production.

which is not an inconsistency, as might be supposed, for their material is in constant circulation and therefore truly fluent. One of the most characteristic of volcanic phenomena is the "crater glow"—that searchlight projection of the lava's luminosity whose reflection by the vapor clouds so closely resembles true flame. It is here included as constituting a precise indication of the presence of active lava in a crater to which a near approach may be inconvenient. Terminal overflow—a common occurrence at some volcanoes, especially during their period of growth,—and the more frequent out-flow from lateral vents, are provided with subdivision into the two main types of lava—the smoothly undulating or ropy "pahoehoe" and the bristling, disunited surface "a–a." Finally we have the phenomenon of viscous extrusion in the form of domes, spines, etc. (Pelée, Bogoslof, etc.)

"Electric" effects are inevitable whenever a powerful gaseous emission is accompanied by abundant detritus, the volcanic lightning appearing in linear flashes (Vesuvius 1906) or as globes of fire (Stromboli 1907) or in stellar form (Pelée 1902.) When the "pino," as a whole, acquires high potential, the silent discharge from pointed objects—St. Elmo's Fire—is frequently seen (Vesuvius 1906).

In the "Seismic" division, volcanic earthquakes are subdivided—for convenience in the case of representing an eruption with a single diagram—into premonitory, concomitant and consecutive. Bradyseismic phenomena involve local elevation or depression which may be transient (Vesuvius 1906) or persistent (Usu–san 1910). Lastly, volcanic "Tsunami," or sea waves, may be of great magnitude and destructiveness. (Krakatoa 1883).

The so-called "Solfataric" phase of volcanism is of greater importance than is generally supposed, especially as regards the primary fumaroles which develop in communication with the interior. These may continue in operation through long periods of external repose, during which time they serve as indicators of the internal conditions. Those of the secondary type, forming on erupted lava or upon accumulations of elastic ejecta, have, necessarily, a more ephemeral existence although they may, for a time, exhibit the same temperatures and characteristics as those of the primary type. Flame-emitting fumeroles have been, perhaps, the least studied of all the phenomena relating to this interesting phase of volcanic action.

"Degradation" and deformation of the volcanic edifice may occur through demolition, subsidence or collapse, either terminal, (Vesuvius 1906) lateral, (Vesuvius, Etna, Santa Maria, etc.) or subsurface (Bogoslof, Krakatoa, etc). By processes of translocation, the materials left or deposited upon the upper

parts of the mountain are gravitationally transported to lower and more peripheral resting places, forming hot ash flows, if of freshly erupted substances and, in any case, dry avalanches, of which a variation is constituted by the equally imposing, but often less directly observable, inter-crateric slides. If these last are of considerable magnitude, the result may be an external ash cloud greatly resembling those due to explosion, and it is important that the two should not be confounded. With the advent of water the translocation is effected by the mud lavas which so frequently form a highly destructive adjunct to an eruption. The diagram key terminates with the item of true landslides, of volcanic causation, which have been frequent in Japan.

In illustration of this diagrammatic method, twelve examples are reproduced on Plates I to IV (two-thirds size) a glance at which will be more explanatory than many pages of description. Attention is called to the comparison of the consecutive outbreaks of Stromboli and their contrast with the effusive eruption of Etna; to the still greater difference between the extreme types Kilauea and Krakatoa; and to the phase variations in the progress of the great Vesuvian event of 1906, for the full analysis of which even more diagrams might profitably be employed. It is, in fact, highly desirable that the charts be used freely and that, at every visit to a vantage point of observation, a diagram should be plotted. It will scarcely be necessary to state that the charts need only be marked in the field and the final diagram filled in at leisure and after mature consideration. It is recommended that the intercept lines be drawn before the insertion of the letters and numbers. These last may be done in red ink, if desired, which gives a lesser interference with the figures, or the circles may be done in red, which is very effective. The circles can easily be filled with pen and ink—an operation which the employment of a lens will facilitate and expedite.

Very elegant diagrams for lantern projection may be made by coloring, on the slide, those circles which would otherwise be blackened. The diagram, in this case, is to be formed on the card by the intercept lines and other markings but without blackening the circles. This is then photographed, the slide is made, and then the diagram circles are filled in with transparent colors. Suitable tints are the following, beginning at the upper radiant and proceeding clock-wise: violet, orange, red, green, purple or black, yellow, blue, brown.

It is, perhaps, inevitable that each living investigator would have worked out a somewhat different diagrammatic method, as personal experience is always vivid and necessarily affects the perspective of a world-wide volcanism. It is only by trial

on a large scale under actual working conditions that the value of a new process can be determined, and, to this end, the writer is prepared to furnish these charts gratis, in several languages, to investigators, and will endeavor to keep a supply on hand at all observatories or stations at volcanic centers, or with the local authorities, for free distribution to visiting scientists.

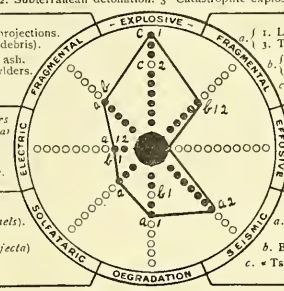
Believing that a special punishment is reserved for those who lightly or unworthily bring forward any new thing, the writer has labored to produce a method which should include all essentials without undue complication and without the sacrifice of workability, bearing constantly in mind the not infrequent moments of his own observations and seeking the counsel of practical fellow workers, for whose kindly aid he is duly grateful.

Posillipo, Naples, October, 1913.

VOLCANO
STROMBOLI.

VOLATILE AND AERIAL
a. 1. Burning gases – true flames. 2 Transparent bluish vapor.
b. 1. Opaque vapor cloud - the white « panache ».
2. Light explosive effects - puffs, rings, vortices.
c. 1. Strong explosive effects – aerial concussion.
2. Subterranean detonation. 3 Catastrophic explosion.

DATE
APRIL – MAY
1907.



a. Dark jets, volutes, spear-head projections. (chaotic ejectamenta – cone debris).
b. The ash « pino ». Showers of ash.
1. Large angular blocks & bowlders.
c. 1. Pisolites. 2. Mud showers.

a. 1. Lava fountain jets. 2. Pele's Hair. 3. Thread-lace «limu». 4. Pele's Tear-drops.
b. 1. Vitreous sand. 2. Lapilli & scoriae. 3. Bombs & figured projectiles.
c. 1. Pumice. 2. Nuées ardentes.

a. Volcanic lightning { 1. *Linear flashes* 2. *Globe* 3. *Stellar*
b. Detonation { 1. *Sharp crackle.* 2. *Heavy thunder.*
c. Silent discharge – *St Elmo's Fire.*

a. Inter-crater lava-flows. 1. Lava lakes.
b. The « Crater-glow » – pseudo flame.
c. Terminal overflow { 1. *pahoehoe.*
d. Outflow, lateral vents { 2. *a-a type.*
e. Viscous extrusion – *Spines, domes, etc.*

a. Fumaroles – primary type (*developed on volcanic channels*).
b. Fumaroles – secondary type (*an erupted lava or clastic ejecta*)
c. Flame-emitting fumaroles.

a. Volcanic earthquakes { 1. *Premonitory.* 2. *Concomitant.* 3. *Consecutive.*
b. Bradyseisms. 1. *Transient.* 2. *Persistent.*
c. « Tsunami » of volcanic causation.

a. Demolition, subsidence, collapse. 1. *Terminal* 2. *Lateral.* 3. *Subsurface*
b. Translocation { 1. *Hot ash flows & dry avalanches.* 2. *Inter-crateric slides.* 3. *Mud lavas.*
c Landslides of volcanic causation.

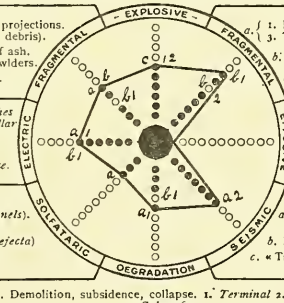
DIAGRAM CHART
(*Perret system*)
of Volcanic Activity
(*Physical*)

OBSERVER
PERRET.

VOLCANO
STROMBOLI.

VOLATILE AND AERIAL
a. 1. Burning gases – true flames. 2. Transparent bluish vapor.
b. 1. Opaque vapor cloud - the white « panache ».
2. Light explosive effects - puffs, rings, vortices.
c. 1. Strong explosive effects – aerial concussion.
2. Subterranean detonation. 3 Catastrophic explosion.

DATE
JULY – AUG.
1912.



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b. The ash « pino ». Showers of ash.
1. Large angular blocks & bowlders.
c. 1. Pisolites. 2. Mud showers.

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a. Demolition, subsidence, collapse. 1. *Terminal* 2. *Lateral.* 3. *Subsurface.*
b. Translocation { 1. *Hot ash flows & dry avalanches.* 2. *Inter-crateric slides.* 3. *Mud lavas.*
c. Landslides of volcanic causation.

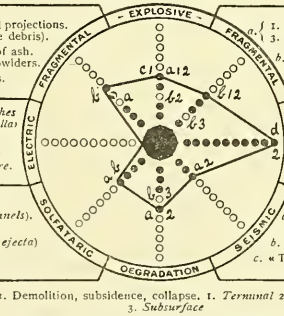
DIAGRAM CHART
(*Perret system*)
of Volcanic Activity
(*Physical*)

OBSERVER
PERRET.

VOLCANO
ETNA

VOLATILE AND AERIAL
a. 1. Burning gases – true flames. 2. Transparent bluish vapor.
b. 1. Opaque vapor cloud – the white « panache ».
2. Light explosive effects - puffs, rings, vortices.
c. 1. Strong explosive effects – aerial concussion.
2. Subterranean detonation. 3 Catastrophic explosion.

DATE
MARCH – APRIL
1910.



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b. The ash « pino ». Showers of ash.
1. Large angular blocks & bowlders.
c. 1. Pisolites. 2. Mud showers.

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c. Flame-emitting fumaroles.

a. Volcanic earthquakes { 1. *Premonitory.* 2. *Concomitant.* 3. *Consecutive.*
b. Bradyseisms. 1. *Transient.* 2. *Persistent.*
c. « Tsunami » of volcanic causation.

a. Demolition, subsidence, collapse. 1. *Terminal* 2. *Lateral.* 3. *Subsurface*
b. Translocation { 1. *Hot ash flows & dry avalanches.* 2. *Inter-crateric slides.* 3. *Mud lavas.*
c Landslides of volcanic causation.

DIAGRAM CHART
(*Perret system*)
of Volcanic Activity
(*Physical*)

OBSERVER
PERRET

VOLCANO
TENERIFFE

VOLATILE AND AERIAL
a 1 Burning gases – true flames, 2 Transparent bluish vapor.
b. 1. Opaque vapor cloud – the white «panache».
2. Light explosive effects – puffs, rings, vortices.
c. 1. Strong explosive effects – aerial concussion.
2. Subterranean detonation. 3 Catastrophic explosion.

DATE
NOVEMBER
1909.

a. Dark jets, volutes, spear-head projections. (chaotic ejectamenta – cone debris).
b. The ash «pino». Showers of ash.
1. Large angular blocks & bowlders.
c. 1. Pisolites. 2. Mud showers.

a. 1. Lava fountain jets. 2. Pele's Hair
b. 3. Thread-lace «limu». 4. Pele's Tear-drops.
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3. Bombs & figured projectiles.
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o Volcanic earthquakes 1. *Premonitory.* 2. *Concomitant.* 3. *Consecutive.*
b. Bradyseisms. 1. *Transient*, 2. *Persistent.*
c. «Tsunami» of volcanic causation.

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b. Translocation 1. *Hot ash flows & dry avalanches.* 2. *Inter-crateric slides.* 3. *Mud lavas.*
c. Landslides of volcanic causation.

DIAGRAM CHART
(*Perret system*)
of Volcanic Activity
(*Physical*)

OBSERVER
PERRET

VOLCANO
KILAUEA

VOLATILE AND AERIAL
a 1. Burning gases – true flames. 2. Transparent bluish vapor.
b. 1. Opaque vapor cloud – the white «panache».
2. Light explosive effects – puffs, rings, vortices.
c. 1. Strong explosive effects – aerial concussion.
2. Subterranean detonation. 3 Catastrophic explosion.

DATE
JULY
1911.

a. Dark jets, volutes, spear-head projections. (chaotic ejectamenta – cone debris).
b. The ash «pino». Showers of ash.
1. Large angular blocks & bowlders.
c. 1. Pisolites. 2. Mud showers.

a. 1. Lava fountain jets. 2. Pele's Hair.
3. Thread-lace «limu». 4. Pele's Tear-drops.
b. 1. Vitreous sand. 2. Lapilli & scoriae.
3. Bombs & figured projectiles.
c. 1. Pumice. 2. Nuées ardentes.

a. Volcanic lightning 1. *Linear flashes* 2. *Globe* 3. *Stellar*
b. Detonation 1. *Sharp crackle.* 2. *Heavy thunder.*
c. Silent discharge – *St Elmo's Fire.*

a. Inter-crater lava-flows. 1. Lava lakes.
b. The «Crater-glow» – pseudo flame.
c. Terminal overflow 1. *pahoehoe.*
d. Outflow, lateral vents 2. *a-a type.*
e. Viscous extrusion – *Spines, domes, etc.*

a. Fumaroles – primary type (*developed on volcanic channels*).
b. Fumaroles – secondary type (*on erupted lava or clastic ejecta*)
c. Flame-emitting fumaroles.

a. Volcanic earthquakes 1. *Premonitory.* 2. *Concomitant.* 3. *Consecutive.*
b. Bradyseisms. 1. *Transient*, 2. *Persistent.*
c. «Tsunami» of volcanic causation.

a. Demolition, subsidence, collapse. 1. *Terminal* 2. *Lateral.* 3. *Subsurface.*
b. Translocation 1. *Hot ash flows & dry avalanches.* 2. *Inter-crateric slides.* 3. *Mud lavas.*
c. Landslides of volcanic causation.

DIAGRAM CHART
(*Perret system*)
of Volcanic Activity
(*Physical*)

OBSERVER
PERRET.

VOLCANO
KRAKATOA

VOLATILE AND AERIAL
a 1. Burning gases – true flames. 2 Transparent bluish vapor.
b. 1. Opaque vapor cloud – the white «panache».
2. Light explosive effects – puffs, rings, vortices.
c. 1. Strong explosive effects – aerial concussion.
2. Subterranean detonation. 3 Catastrophic explosion.

DATE
AUGUST
1883.

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b The ash «pino». Showers of ash.
1. Large angular blocks & bowlders.
c. 1 Pisolites. 2. Mud showers.

a. 1. Lava fountain jets. 2. Pele's Hair.
3. Thread-lace «limu». 4. Pele's Tear-drops.
b. 1. Vitreous sand. 2. Lapilli & scoriae.
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b. Bradyseisms. 1. *Transient*, 2. *Persistent.*
c. «Tsunami» of volcanic causation.

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b. Translocation 1. *Hot ash flows & dry avalanches.* 2. *Inter-crateric slides* 3. *Mud lavas.*
c. Landslides of volcanic causation.

DIAGRAM CHART
(*Perret system*)
of Volcanic Activity
(*Physical*)

OBSERVER
DESCRIPTION

VOLCANO
VESUVIUS

VOLATILE AND AERIAL

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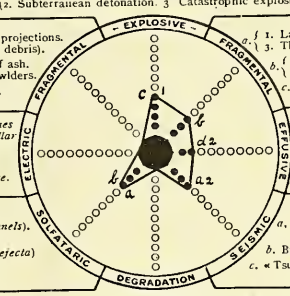
b. 1. Opaque vapor cloud – the white «panache».
2. Light explosive effects – puffs, rings, vortices.
c. 1. Strong explosive effects – aerial concussion.
2. Subterranean detonation. 3 Catastrophic explosion.

DATE
APR. 4, 1906.
A. M.



a. Dark jets, volutes, spear-head projections. (chaotic ejectamenta – cone debris).
b. The ash «pino». Showers of ash.
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DIAGRAM CHART
(*Perret system*)
of Volcanic Activity
(*Physical*)

OBSERVER
PERRET

VOLCANO
VESUVIUS

VOLATILE AND AERIAL

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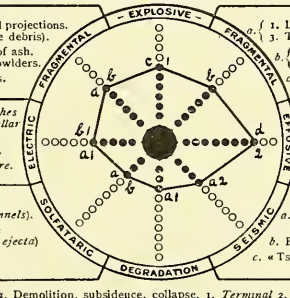
c. 1. Strong explosive effects – aerial concussion.
2. Subterranean detonation. 3 Catastrophic explosion.

DATE
APR. 6, 1906.
2.00 P.M.



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1. Large angular blocks & bowlders.
c. 1. Pisolites. 2. Mud showers.

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DIAGRAM CHART
(*Perret system*)
of Volcanic Activity
(*Physical*)

OBSERVER
PERRET.

VOLCANO
VESUVIUS

VOLATILE AND AERIAL

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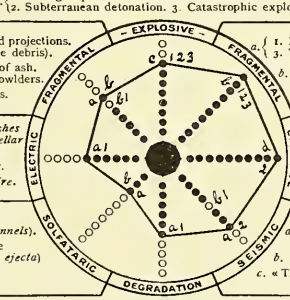
2. Light explosive effects – puffs, rings, vortices.
c. 1. Strong explosive effects – aerial concussion.
2. Subterranean detonation. 3. Catastrophic explosion.

DATE
APR. 7, 1906.
10.45 P.M.



a. Dark jets, volutes, spear-head projections. (chaotic ejectamenta – cone debris).
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DIAGRAM CHART
(*Perret system*)
of Volcanic Activity
(*Physical*)

OBSERVER
PERRET

VOLCANO
VESUVIUS

VOLATILE AND AERIAL
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c. 1. Strong explosive effects — aerial concussion.
2. Subterranean detonation. 3 Catastrophic explosion

DATE
APR. 8, 1906.
3.30 A.M.

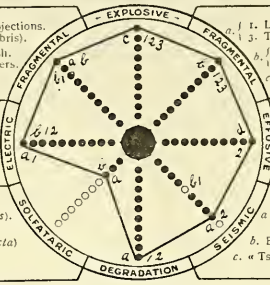

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DIAGRAM CHART
(Perret system)
of Volcanic Activity
(Physical)

OBSERVER
PERRET.

VOLCANO
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VOLATILE AND AERIAL
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2. Light explosive effects – puffs, rings, vortices.
c. { 1. Strong explosive effects — aerial concussion.
2. Subterranean detonation. 3 Catastrophic explosion.

DATE
APR. 8, 1906.
3.00 P.M.

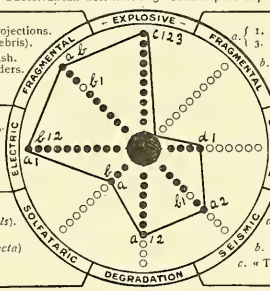

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DIAGRAM CHART
(Perret system)
of Volcanic Activity
(Physical)

OBSERVER
PERRET.

VOLCANO
VESUVIUS

VOLATILE AND AERIAL
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DATE
APR. 9, 1906.
3.00 P.M.

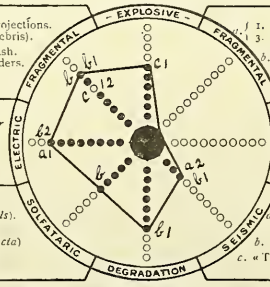

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DIAGRAM CHART
(Perret system)
of Volcanic Activity
(Physical)

OBSERVER
PERRET.

Art. IV.—*A Nipa-palm in the North American Eocene;** by Edward W. Berry.

The existing Nipa-palm, which Sir Joseph D. Hooker describes so graphically in his Himalayan Journals (1891), is an exceedingly interesting plant to the ecologist, the systematist, the geographer and the geologist. To the ecologist because of its unusual habitat in brackish or marine waters. To the systematist because of its somewhat isolated position among the palms and its supposed affinity with the Pandanaceæ. To the plant-geographer and the geologist because of its distribution by ocean currents and the extended range of its closely allied ancestors of Eocene times.

The genus Nipa has but a single species in the existing flora, that is to say, it is monotypic, and monotypic genera have been found to have an exceedingly interesting and instructive geological history whenever it has been possible to decipher the records of the past bearing upon that history.

The modern Nipa plant is a stemless palm with a graceful cluster of gigantic, pinnately compound leaves, sometimes as much as twenty-five feet in length, rising directly above the surface of the water. It inhabits the tidal waters of the Indian ocean, forming brakes or thickets on the low swampy islands of the Sunderbunds, and ranges from India through the Malay archipelago to the Philippines, competing with the various species of mangroves for possession of the tidal flats. The female inflorescence consists of a close cluster of large obovate ribbed nuts, forming a spherical cluster or head that is nine or ten inches in diameter. The water in the delta of the Ganges is often covered with these floating nuts just as were the deltas around the Paris basin in Eocene times. Hundreds of the pyritized nuts of Nipadites are found in the London clays of Sheppey, which represents part of an Eocene estuary. As long ago as 1757 Parsons† mentioned these English fossil fruits and they were well figured by Parkinson‡ in 1811, who compared them with the fruits of the existing Cocos. Similar fossils from Belgium were described and figured by Burtin§ under the name of Coco-nuts in 1784. Brongniart‖ in 1828 proposed three species for the reception

* Published with the permission of the Director of the U. S. Geological Survey.

† Parsons, An account of some fossil fruits and other bodies found in the island of Sheppey, Phil. Trans. Roy. Soc. Lond., vol. 1, pt. i, p. 396, 1757.

‡ Parkinson, Organic Remains of a former World, London, 1811, p. 448, pl. 6, 7.

§ Burtin, Oryctographie de Bruxelles, p. 118, pl. 30A, 1784.

‖ Brongniart, Prodrome d'une Histoire des Végétaux fossiles, pp. 121, 135, 1828.

of these fossils—*Cocos Burtini* for Burtin's Belgian specimens, *Cocos Parkinsonis* for Parkinson's English specimens, and a third, *Cocos Faujasii*, for the French specimens described and figured by Faujas in the first volume of the Annals of the Paris Museum. In 1837 Bronn* substituted the generic term Cocites for Brongniart's term Cocos.

Meanwhile Thunberg in 1782 had given a somewhat meagre description of the existing Nipa-palm. This preliminary information was much amplified in 1819 in a memoir by Billardière published in the Paris Museum memoirs and devoted entirely to the Nipa. Hence in 1840 when Bowerbank monographed the fossil fruits and seeds from the famous deposits of the Island of Sheppey, he was familiar with the modern Nipa and had even seen specimens of its fruits that had been brought to England by travellers. He therefore renamed the fossils Nipadites and described and figured no less than thirteen different species from the deposits of the old Eocene delta represented by the London clays. These were based, for the most part, on variations of form and condition of preservation. Modern authors have greatly reduced the ranks of Bowerbank's species, recognizing that the variations recorded were largely dependent on the position and relative development of the individual fruits in the inflorescence or head.

In 1855 Massalongo† found similar fossil fruits in the Tertiary of the province of Verona in northern Italy. He did not recognize their identity with the English, French and Belgian fossils and described them under the genus Palæokeura which he referred to the Pandanaceæ. More recently Schmalhausen‡ has described Nipadites from the Spondylus zone of the Eocene at Kiew in southern Russia, and Bonnet§ has described a gigantic form from Giouchy in the Mokattam Mountains east of Cairo in Egypt (étage Lutetien).

A complete bibliography of the publications devoted to Nipadites would include a considerable number of additional titles, of which I will mention but two—one a very satisfactory revision of the fossil forms by Rendle‖ that appeared in 1893 and the second a monograph of the Belgian forms by Seward and Arber¶ which was published in 1903. The latter authors

* Bronn, Lethaea geognostica, vol. i, p. 861, 1737.

† Massalongo, Sopra un nuova genere di Pandanee fossili della Provincia Veronese.

‡ Sehmalhausen, Pal. Abhandl. Dames and Kayser, vol. i, p. 12, pl. 30 (3), figs. 2–6, 1884.

§ Bonnet, Bull. Mus. d'Hist. Nat., Paris, 1904, pp. 499–502, 2 figs.

‖ Rendle, Revision of the genus Nipadites, Bowerbank, Journ. Linn. Soc. Lond., vol. xxx, 1893.

¶ Seward and Arber, Les Nipadites des couches Écocènes de la Belgique. Mém. Musée Roy. d'Hist. nat. Belge., ii, 1903.

unite all of the Belgian forms, which according to Rutot range from the étage Paniselien through the Bruxellien, Laekenien and Wemmelien, under the single specific name of *Nipadites Burtini* Brongniart (1849, p. 88).

The foregoing is a brief résumé of the previous discoveries relating to Nipadites all of which have been confined to Europe and Africa until the present time. During the past summer, in company with Dr. E. N. Lowe, State Geologist of Mississippi, I collected fruits of Nipadites from a fossiliferous outcrop of clay of upper Wilcox age exposed near

FIG. 1.

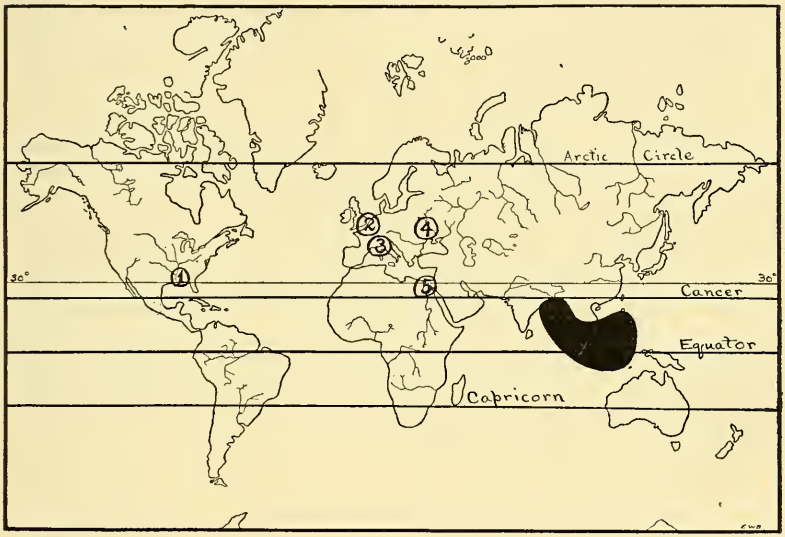

FIG. 1. Sketch-map showing the approximate distribution of the Nipa-palm (solid black) and the Eocene occurrences of Nipadites. (1)=Mississippi, (2)=London, Belgian and Paris basins, (3)=southern France and northern Italy, (4)=southern Russia, (5)=northern Egypt.

Grenada in Grenada County, northern-central Mississippi. Ever since I commenced working on the Wilcox flora. several years ago, I have been on the lookout for Nipadites, which is such a striking element in the Eocene northward extension of tropical floras in Europe. Its discovery in America is of considerable importance because of the certainty with which it testifies to the physical conditions of the remote period when it grew along the shores of the great Mississippi Eocene Gulf. The American fruits cannot be separated from those of *Nipadites Burtini* Brongniart to which they are referred as the variety *umbonatus* of Bowerbank. They are obovate in outline with a narrowed truncated base and a broadly rounded

umbilicate apex, and range from 5^{cm} to 8^{cm} in length and from 3^{cm} to 5^{cm} in maximum width. The surface is more or less fibrous and obscurely angled.

The discovery of Nipadites in the Eocene of Mississippi serves to fix more definitely the age of the Wilcox Group in terms of European chronology. It also emphasizes the lagoon and estuarine character of the Wilcox deposits of the upper Mississippi Gulf and the sub-tropical character of the strand flora that flourished along the margin of the low-lying continental lands that bordered the Gulf. It also raises an interesting question regarding the path of migration of Nipadites. Since these fruits appear to be found in older deposits abroad the genus is very likely of oriental origin. It could have reached the Western Hemisphere by two routes. The fruits may have floated across the Atlantic, which would hardly be possible if the Atlantic currents of the Eocene were at all similar to those of the present time. If there was more or less of an Atlantic equatorial land-mass, as a number of geologists have advocated, the foregoing migration would have been a simple matter. On the other hand, and this seems to me to be the more probable hypothesis, the range of these palms may have covered a large part of Oceanica during the late Cretaceous and early Eocene, and they may have been carried by ocean currents across the submerged lands of what is now Central America and into the Eocene Mississippi Gulf. The accompanying sketch-map (fig. 1) shows in a generalized but graphic way the range of the existing Nipa and the early Tertiary occurrences of Nipadites.

Johns Hopkins University, Baltimore.

ART. V.—*A Modification of the Usual Method of Correcting Silica for included Salts;* by S. B. KUZIRIAN.

[Contributions from the Kent Chemical Laboratory of Yale Univ.—cclii.]

WHEN silica, liberated by the action of hydrochloric acid upon the product of fusion of a silicate with an alkali carbonate, is made insoluble and separated by the usual subsequent treatment,—viz., evaporation, desiccation at 110°, extraction with dilute hydrochloric acid and water, filtration, and repeated washing with distilled water,—it invariably contains foreign material which after strong ignition consists essentially of oxides, free or combined with the silica. If the silica is volatilized by treatment with hydrofluoric acid and sulphuric acid, the included material is composed of sulphates which remain as such or are changed to oxides in a subsequent ignition. If the constituents of this residue were definite and correctly determinable, it would be possible to calculate the weight of the oxides as they exist in the strongly ignited silica, and to make the proper correction; but it is a difficult task to make a correct analysis of a residue which sometimes does not exceed two to three milligrams and may contain iron, aluminum, manganese, titanium, magnesium, sodium, potassium, etc. In order to avoid making the quantitative analysis of this small residue of sulphates and oxides, it has been an approved procedure to blast the silica to constant weight and then to assume that after the prolonged blast ignition the impurities are left in the form of oxides. Then, after the removal of the silica with sulphuric and hydrofluoric acids, the remaining sulphate residue is also blasted to constant weight, and the assumption is made that this latter step will transform the sulphates of the residues into their oxides. The weight of silica is then found by difference. It will be shown in the following account of experimental work that the residue obtained after treatment of the blasted silica with sulphuric and hydrofluoric acids and blasting does not accurately represent the amount of included material as it is ordinarily weighed with the silica.

In the presence of moisture from the Bunsen burner or the blast-lamp, chlorides are slowly decomposed with evolution of hydrochloric acid and the simultaneous formation of metallic oxides or, in the case of the alkali metals, hydroxides, which may then enter into combination with any suitable non-metallic oxide with which they are in contact. Silica containing traces of soluble alkali chlorides may, on strong ignition, gradually combine with the metallic oxides formed, as has been shown in a previous paper.* The assumption that the impurity in the silica, contaminated by chlorides when it is separated, consists after the ignition exclusively of oxides is, therefore, well founded.

* This Journal, xxxvi, 598, 1913.

Alkali sulphates, on the other hand, do not yield definite and weighable oxides on ignition. Moreover, they may volatilize as such at the high temperature of the blast-lamp. The experiments of Table I show that the presence of silica does not materially change this characteristic of alkali sulphates, and that when a small amount of an alkali chloride is added in solution to ignited silica, and the mixture evaporated to dryness and treated with sulphuric acid, the residue left after ignition with the Bunsen burner is essentially the neutral sulphate.

TABLE I.

Silica ignited with Bunsen burner 1/2 hour grm.	Silica ignited with blast-lamp 20 mm. grm.	Na_2SO_4 equivalent to NaCl added grm.	Increase in weight of silica after addition of NaCl, treatment with H_2SO_4 and ignition with Bunsen burner grm.	Error when the impurity is corrected as Na_2SO_4 grm.
0·4779	0·4776	0·0122	0·0131	+0·0009
0·5316	0·5315	0·0122	0·0131	+0·0009
0·5266	0·5264	0·0122	0·0122	0·0000
0·5311	0·5293	0·0115	0·0115	0·0000

That elements other than sodium and potassium, present originally with the silica as chlorides and converted to sulphates by the action of sulphuric acid and gentle ignition, may be recovered essentially as sulphates after treatment with sulphuric and hydrofluoric acids and gentle ignition, is shown in Table II.

TABLE II.

Silica ignited with Bunsen burner 1/2 hour grm.	Silica ignited with blast-lamp 20 min. grm.	Sulphate equivalent to chloride added grm.	Sulphate determined by increase in weight of silica grm.	Sulphate left after removing silica by H_2SO_4+HF grm.
		$BaCl_2$ added.		
0·5290	0·5290	0·0103	0·0098	0·0104
		$CaCl_2$ added.		
0·5576	0·5572	0·0121	0·0114	0·0118
0·5351	-----	0·0242	0·0218	0·0226
0·5486	-----	0·0242	0·0242	0·0234
0·5413	-----	0·0242	0·0228	0·0234
0·5486	0·5486	0·0242	0·0242	-----
		$MgCl_2$ added		
0·5441	0·5436	0·0200	0·0195	0·0197
0·5446	-----	0·0200	0·0215	0·0220
0·5456	0·5456	0·0200	0·0203	-----
		$AlCl_3$ added.		
0·5456	-----	0·0195	0·0200	0·0195
0·5447	-----	0·0195	0·0192	0·0205
0·5490	0·5490	0·0195	0·0188	-----

As is well known, sulphates other than alkali sulphates, lose the acidic oxide, more or less according to the conditions, when submitted to ignition with the blast-lamp. While prolonged blast-ignition may bring about a complete transformation of the sulphates of iron, aluminium, chromium, and titanium to the respective oxides, the refractory alkali sulphates, as well as the sulphates of magnesium, calcium, and barium in large degree, will remain in the condition of sulphates (though the alkali sulphates may volatilize appreciably), and the correction for silica as ordinarily applied will be in error by an amount approximately equal to that of the sulphur trioxide combined in the sulphates.

The source of error, inherent in the usual method of applying corrections to the ignited silica, may be largely avoided by the introduction of a slight modification of the treatment. This modification consists essentially in treating the ignited silica with sulphuric acid, gently igniting again before weighing, and in igniting under exactly the same conditions the sulphate residues left after the removal of the silica in the usual way. That is to say, the included impurities of the silica must be transformed before weighing into the condition in which they will be left when the silica is removed by sulphuric acid and hydrofluoric acid. This can be accomplished by adding a few drops of dilute sulphuric acid to the well ignited impure silica, evaporating the excess of the acid slowly over a radiator and igniting the residue by means of a Bunsen burner, before weighing the residue. Then, after the removal of the silica in the usual manner, the sulphate residue left is ignited, at the same temperature and for the same duration of time as was the silica, and then weighed. From the weight of the silica plus the impurity before the treatment with sulphuric acid and hydrofluoric acids and that of the residue after that treatment the weight of the silica is found by difference.

Table III contains the details of experiments in which silica was fused with six times its weight of sodium carbonate, the melt treated with hydrochloric acid; the mixture evaporated; the residue desiccated (at 110° (A) or, in presence of acetic anhydride, at 137° (B)), and extracted as usual with hydrochloric acid; the precipitate filtered off and washed; and the filtrate treated again like the original solution of the melt for the recovery of silica soluble in the former operation. The residues (first, second, and total) and the error which results from calling these residues oxide instead of sulphate and subtracting their weight from that of the ignited silica, according to the usual method of making the correction, are shown.

Table III.

SiO_2 (blasted) taken grm.	Residue left by H_2SO_4 + HF treatment of first precipitate grm.	Residue left by H_2SO_4 + HF treating of second precipitate grm.	Sum of residues grm.	Error which results from calling the residues oxide instead of sulphate grm.
		A		
		Desiccation at 110°.		
0·5302	0·0010	0·0012	0·0022	+0·0013
0·5211	0·0010	0·0010	0·0020	+0·0012
0·5440	0·0010	0·0012	0·0022	+0·0013
0·5351	0·0010	0·0002	0·0012	+0·0007
0·5436	0·0010	0·0013	0·0023	+0·0014
		B		
		Desiccation at 137° in acetic anhydride.		
0·5520	0·0010	0·0003	0·0013	+0·0008
0·5452	0·0010	0·0010	0·0020	+0·0012
0·5347	0·0010	0·0005	0·0015	+0·0009
0·5521	0·0010	0·0005	0·0015	+0·0009

These errors, which are not inappreciable, were found when the silica was separated, as well as possible, from sodium chloride alone. When chlorides of other elements, such as magnesium, calcium, and aluminium, are present the silica separated is likely to be also contaminated with these salts which, by the ordinary treatment, will be transformed to oxides when the silica is ignited and to sulphates when the silica is removed; and these sulphates will be more or less refractory under ignition, according to their natures and to the duration and temperature of the ignition. The errors shown above for the case in which sodium chloride is the only contaminating salt are likely to be magnified in the analysis of ordinary silicates of complex composition. The proposed modification of treatment will, therefore, lead to a more accurate application of the correction for impurities included in the silica. In this procedure it is not necessary to blast either the silica or the residue before and after the removal of silica as silicon fluoride. The Bunsen burner will give a temperature sufficiently high to volatilize the excess of sulphuric acid and to break up the acidic and pyrosulphates of the alkali elements. The included salts being weighed as sulphates, or as sulphates broken up to practically the same extent in both ignitions, the correction to be applied will be reasonably accurate.

Art. VI.—*Electrometry with the Displacement Interferometer*;* by Carl Barus.

1. *Introductory.*—The possibility of compensating any displacement of the mirror N by a corresponding displacement of the micrometer M, i. e. the fact that the ellipses are never lost in a properly adjusted displacement interferometer, for any amount of motion of the mirror N, however sudden it may be, suggests the use of this method for electrometry. Some time ago I made† experiments of this kind, using the device of the absolute electrometer for the purpose. A mirror was attached to the disk and the force of restitution obtained from a pendulum suspension for parallel motion. It appeared that the apparatus is very insensitive for small potentials, even with the use of the interferometer.

A cylindric or lamellar form, such as is usually referred to in constructing the theory of the instrument, seemed to be specially available; but the sensitiveness here also. if torsion systems are excluded, is unexpectedly small, unless (as in Thomson's original apparatus) excessive charges are given to the needle, a procedure which introduces its own difficulties. Nevertheless I constructed the apparatus in a variety of forms, each of which will be described, in turn, in order to ascertain in how far the sensitiveness, which may be estimated from theory, may be actually realized in practice; i. e., to actually confront the instrumental difficulties of the problem, with a view to the use of the method in absolute measurements of potential.

2. *Cylindric electrometer. Movable cylinder without.*—Figs. 1 and 2, both sectional elevations, show the first form of electrometer in which the movable cylinder (usually highly charged) is external to the fixed cylinders h and i carrying opposite charges. The latter are supported on hard rubber pillars, u and v, rising from the adjustable feet q, of which r and s are the leveling screws and the set screw. The whole arises from a narrow base of brass plate AA. On this base the braced scaffolding of very thin brass pipe efg is also mounted, grasped above by the light cross rod d. This makes a light but very firm support for the two parallel horizontal rods of hard rubber cc, secured at b and carrying the revolvable brass rollers or reels aa snugly. From aa the threads of very thin copper wires yy $\cdot 007^{cm}$ in diameter depend, their lowest point being attached to the cylinder kk, making of it a pendulum. To obviate torsional vibration the wires yy con-

* Abridged from a Report to the Carnegie Institution, Washington, D. C.
† Physical Review, iv, p. 400, 1897.

verge on their front elevation from *aa* to the top *tt* of the cylinder, while in their side elevation they are rigorously parallel and equally long. They may be lengthened or shortened by turning the close fitting rollers *aa*, so that the cylinder *kk* may be placed accurately concentric to the cylinders *ih*. The latter may be mounted with a cylinder of wood passed quite through them, which is withdrawn after they are

FIG. 1.

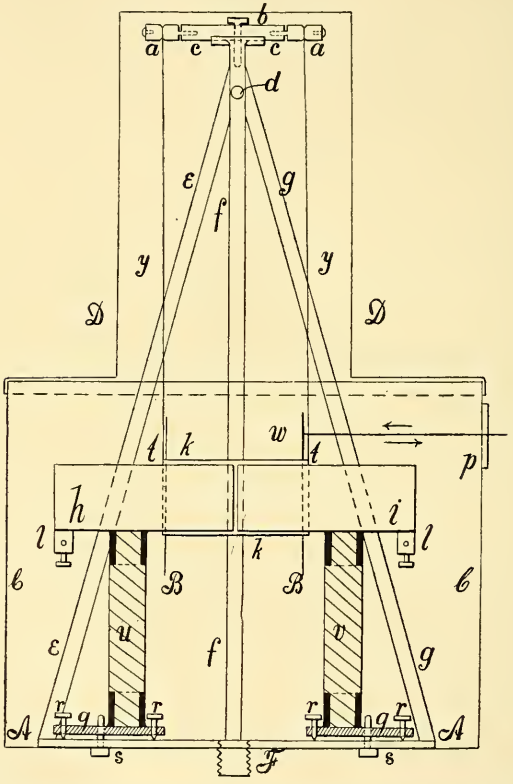

FIG. 1. Cylindrical electrometer, vertical section. Front view.

fastened. The clamp screws *ll* and those at the end of *a* are convenient for charging, the wires passing out of the light tin plate cover *CCDD* through hard rubber cylinders at *Z*. The top *DD* may be lifted off. When there is no danger of induction, *DD* may be removed. The ellipses of the interferometer, in a room free from draft, are quite adequately stationary even without *DD*, a surprising result.

The cylinder *kk* is either of very thin aluminum tubing, or preferably of gilt paper. The wires *yy* pass through small holes at the top ends. To secure adequate damping, thin circular rings of mica or of paper, *BB*, surround the ends, and the front one carries the light mirror *w*, which reflects one of

FIG. 2.

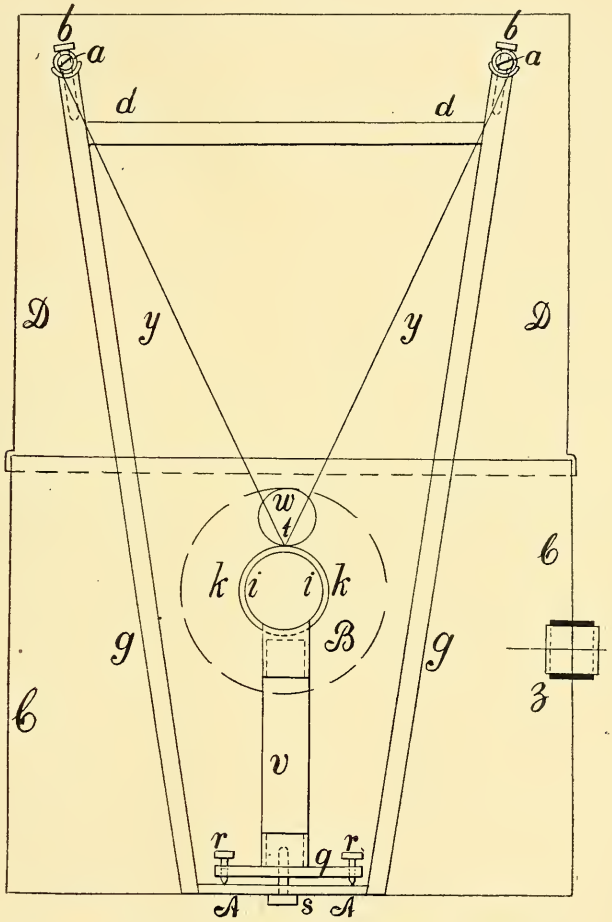

FIG. 2. Cylindrical electrometer, vertical section. Side view.

the component beams of the interferometer, as indicated at the glass window *p*. If liquid damping is desired, in the case of a heavy cylinder, wires ending in a vane may be dropped from one of these disks with the vane in a box of oil below. This

was tried without apparent disadvantage, but a light paper cylinder and air damping is of course preferable, being far more sensitive. The mica B should be somewhat adjustable so that the beam p may be given the proper direction, roughly. The methods for doing this will be described below.

The whole apparatus, covered at least as far as C, was then mounted on one arm of the interferometer by the aid of a large clamp of the ordinary pattern, the clamp having been screwed into the base A at F. As the arm is of gas pipe, F is an ordinary nipple of suitable length. It is advisable to further support the tin case with wood uprights from the table to avoid the effect of tremors due to the vicinity of an active laboratory; but no great difficulty was here encountered. In fact, the ellipses of the interferometer were obtained in all cases after a preliminary rough adjustment of the mirrors with surprising ease, and they were quite as stable and available for measurement as if the mirrors had been rigidly fixed. Naturally this was quite contrary to our anticipations, but it is shown by the large number of experiments made, each of which required a new adjustment.

The measurement consists merely in a compensation of the displacement of the movable mirror on the electrometer, by the micrometric displacement ΔN of the mirror belonging to the other component beam. The center of the displaced ellipses in the field of the telescope is thus brought back to the fiducial sodium line. The compensation admits of an accuracy of about $\Delta N = \cdot 0001$ centimeter without resorting to the interference rings. Other remarks on the optical method are given in the next paragraph.

3. *Cylindrical electrometer; movable cylinder within. Interferometry.*—The frame-work and the mounting here is in general the same as in the preceding case and the movable cylinder kk is the same, but differently suspended. Details must be omitted here and other forms of the instrument (disk pattern, closed field pattern) will be described below.

The general treatment of the displacement interferometer has been given in my earlier papers. The field of the telescope after the appropriate two (of the four) undeviated images of the slit, from front and rear of the grating plate, have been put into coincidence horizontally and vertically (the images being usually bluish and yellowish), contains but three superposed spectra, although there are four white images, two from the front and two from the rear of the plate. For the component beam reflected from the rear face of the grating is not diffracted. It is thus advantageous to eliminate the third spectrum also, and to keep only the two which are superimposed for interference in the field. This may be easily done as follows: the two component beams reflected from the mirror

facing the ruled side of the grating plate usually appear as separated images on the mirror, about 1/8 inch apart, and the one yellowish in color may be blotted out by a small screen near the mirror. As a result of this the stationary interferences which are due to the two beams from the same mirror also vanish. The spectrum is now clear and contains only the interfering superpositions, giving the ellipses their maximum definition.

In other respects the mounting on the interferometer is the same as before, and very little difficulty was experienced in obtaining the ellipses. The top of the case *DD*, here necessarily a square box, may usually be removed without disadvantage. If liquid damping is necessary in case of a heavy cylinder *kk*, the wire with vane may be dropped into a vessel of oil from the rear end of *tt*, the front carrying the mirror.

The usual method of connecting was used for potential measurements, one pole of the experimental cells being alternately earthed as well as one pole of the charging battery. A Mascart key was found very useful. When the needle swings to and fro the ellipses are visible at the extreme elongations of the deflection (if not too large) of the vibrating cylinder. They flash into the field of the telescope at the two ends of it, but are invisible between. The distance apart of the positions of visibility gradually diminishes until they coincide and the cylinder is stationary. If the ellipses are clear, slight motion does not interfere with the measurements, as the mean position is readily determinable in the displacement method. This would not, however, be the case had the evanescence of rings been made the basis of measurement.

4. *Equations. Cylindrical electrometer.* — The equations may be found in the usual manner, and as so little of the field is displaced during deflection they apply with acceptable accuracy. Virtually a small cylindrical shell of uniform field is supposed to disappear on one side to reappear on the other. Hence, let V_3, V_2, and V_1 be the potentials of the two fixed and a movable cylinder (needle) respectively. Let f_{12} denote the electric force between cylinders (2) and (1), and f_{13} the force between cylinders (3) and (1), and R the common radius of the fixed cylinders, r that of the movable cylinder. Hence, if $R-r$ is small,

$$f_{12}=(V_1-V_2)/(R-r)\,;\; f_{13}=(V_1-V_3)/(R-r)$$

If the displacement of the cylinder is dx the changes of potential energy on the two sides are

$$dW_{12}=\frac{R+r}{R-r}\,\frac{V_1-V_2}{8}dx,\quad dW_{13}=-\frac{R+r}{R-r}\,\frac{V_1-V_3}{8}dx$$

and hence the force acting in the direction x if $W = W_{13} + W_{12}$ is after reduction

$$X = \tfrac{1}{8}\frac{R+r}{R-r}\left(V_3 - V_2\right)\left(2V_1 - (V_2 + V_3)\right)$$

On the other hand, the restoring force is for small displacements

$$X = Mgdx/l$$

where M is the mass of the cylinder, l the length of the pendulum suspension; whence if $dx = \Delta N$, in electrostatic units,

$$\left(V_3 - V_2\right)\left(V_1 - \frac{V_3 + V_2}{2}\right) = \frac{4\,Mg\,(R-r)}{l\,(R+r)}\Delta N$$

which is the required equation. Since, if t is the thickness, L the length, and ρ the density of the movable cylinder,

$$\left(V_3 - V_2\right)\left(V_1 - \frac{V_3 + V_2}{2}\right) = \frac{8\,\pi\,Lt\,\rho\,(R-r)}{l\,(1+R/r)}\Delta N$$

the appurtenances, like mirror, etc., being disregarded. A given deflection ΔN will therefore correspond to smaller $V_3 - V_2$ as $R-r$, L, t, are smaller and l and V are larger.

If the instrument is used idiostatically (electrostatic units),

$$\left(V_3 - V_2\right)^2 = \frac{8\,Mg\,(R-r)}{l\,(R+r)}\Delta N$$

If one pole of the cell $V_3 - V_2$ is earthed, $V_2 = 0$, and the deflections on commutation are ΔN and $-\Delta N'$,

$$V_3 = \left(300\right)^2 \frac{4\,Mg\,(R-r)}{V_1\,l\,(R+r)}\frac{\Delta N + \Delta N'}{2} = 300^2 \frac{8\,\pi\,Lt\,\rho\,(R-r)}{V_1\,l\,(1+R/r)}\frac{\Delta N + \Delta N'}{2} \text{ volts.}$$

If the cylinder V_1 is made of paper, the following dimensions seem to be reasonably convenient limits, so that for $\Delta N = \cdot 0001$ centimeter, $L = 5$ cm., $t = \cdot 2$ cm., $\rho = 1$; $l = 100$ cm., $V_1 = 300$ volts, whence

$$V_3 = 3\cdot 8 \times 10^{-4} \text{ volts,}$$

or about 10^{-4} volts per ring.

One should thus be able to measure voltages even within 4×10^{-4}; but on trial the actual limits fall much within this. The use of wide apparatus has the advantage only of diminishing the effect of appurtenances like the mirror, etc. In the practical work below, however, these limits could not be reached for reasons which will appear.

The idiostatic method under the same circumstances, $\Delta N = \cdot 0001$ centimeter, should just measure

$$V_3 = \cdot 5 \text{ volt},$$

so that alternating currents much within 1 volt will apparently be measurable. This method is naturally much less sensitive than the other, but its absolute character and its adaptation to alternating currents are of interest. The sensitiveness of the idiostatic electrometer as here designed, and in the above case of the absolute electrometer, would thus appear to have the same practical limit. In the way of absolute measurement, nothing has been gained.

5. *The Same. Disk electrometer.* In this case a charged disk with a guard ring (the apparatus to be described hereafter, figs. 5 and 6) at potential V_1 is suspended bifilarly, as above, between the two concentric parallel disks of the condenser, at potentials V_3 and V_2. The adjustment may be regarded as the extreme case of the cylinder electrometer with closed ends and the equations will be, necessarily, nearly the same. Let d be the distance apart of the plates of potential V_3 and V_1, D the distance between the plates of potential V_3 and V_2, r the radius of the movable disk. The total energy W of the variable system is then, after reduction

$$W = \frac{r^2}{8\pi} \left\{ \frac{(V_3 - V_1)^2}{d} + \frac{(V_1 - V_2)^2}{D - d} \right\}$$

and the corresponding mechanical force

$$X = \frac{r^2}{8} \left(\frac{V_1 - V_2}{D - d} + \frac{V_3 - V_1}{d} \right) \left(\frac{V_1 - V_2}{D - d} - \frac{V_3 - V_1}{d} \right)$$

which depends essentially on d as well as on D.

Let the disk be in the middle, or $2d = D$, and put $X = Mg\Delta N/l$ as above, where M is now the mass of the disk and appurtenances, ΔN the interferometer displacement, l the length of the bifilar pendulum, and g the acceleration of gravity. Then

$$\left(V_3 - V_2 \right) \left(V_1 - \frac{V_2 + V_3}{2} \right) = \frac{MgD^2}{lr^2} \Delta N$$

Let $V_2 = 0$ and $M = \pi r^2 t \rho$, t being the thickness and ρ the density of the disk, the latter being sufficiently large so that the appurtenances may be ignored. Then on commutation and in electrostatic units, ΔN being the mean displacement,

$$V_3 = \frac{MgD^2}{V_1 l r^2} \Delta N = \frac{\pi t \rho g D^2}{V_1 l} \Delta N,$$

which (for a sufficiently large disk) is independent of its area.

To estimate the limiting sensitiveness the following apparently reasonable values may be inserted

$V_1 = \frac{1}{3}$ els., $t = \cdot 05$ cm., $\rho = 1$, $D = \cdot 1$ cm., $\Delta N = 10^{-4}$ cm., $l = 10^2$ cm. Whence

$$V_3 = 1 \cdot 4 \times 10^{-3} \text{ volts.}$$

The limiting sensitiveness is thus of the same order as in the cylindrical case for the same V_1, as might have been anticipated. It is probable, however, that the present conditions may be more nearly realized in practice, as the apparatus is essentially simpler.

If $V_2 = V_1 = 0$, the idiostatic case is identical with the absolute electrometer.

6. *The closed field electrometer (disk and cylinder combined).* If the two cases of the preceding paragraphs be combined, with the symbols of potential and distance the same as before, the energy of the system is, in electrostatic units,

$$W = \tfrac{1}{8} \left\{ \left(V_3 - V_2 \right)^2 \left(\frac{r^2}{d} + L \frac{R+r}{R-r} \right) + \left(V_1 - V_2 \right)^2 \left(\frac{r^2}{d^1} + L^1 \frac{R+r}{R-r} \right) \right\}$$

and hence the forces become

$$X = \tfrac{1}{4} \left(\frac{r^2}{d^2} + \frac{R+r}{R-r} \right) \left(V_3 - V_2 \right) \left(V_1 - \frac{V_2 + V_3}{2} \right) = \frac{Mg}{l} \Delta N$$

If $V_2 = 0$,

$$V_3 = \frac{4\, Mg\, \Delta N}{V_1 (r^2/d^2 + (R+r)/(R-r))\, l}$$

after commutation, where l is the length of the cylinder. The sensitiveness of this apparatus depends very largely on d, that is upon the disk, in any practical case; but it should be more nearly absolute. Experiments were not made.

7. *Corrections.* The most important consideration to be made here is the effect attributable to the want of symmetry in the orientation of the disk or movable charge, supposing the latter and the plates are quite parallel. Let k be the axial distance of the uncharged disk from the plane midway between the condenser plates (guard ring). In such a case, if the electric displacement is ΔN, the quantity $\Delta = k + \Delta N$ must be added on one side and subtracted on the other, so that $d = D/2 + \Delta$, $d^1 = D/2 - \Delta$ Thus the displacing force is, after reduction,

$$X = \frac{r^2}{2} \left(\frac{V_1 - V_2}{D - 2\Delta} + \frac{V_3 - V_1}{D + 2\Delta} \right) \left(\frac{V_1 - V_2}{D - 2\Delta} - \frac{V_3 - V_1}{D + 2\Delta} \right)$$

which may be further reduced.

If nothing is neglected, and under the assumption of a uniform field, for a positive charge, V_3 corresponding to a displacement ΔN^1 with $V_2 = 0$; and for a negative charge, $-V_3$

corresponding to a displacement $-\Delta N''$, the mean of the equations, $\overline{\Delta N} = \frac{1}{2}(\Delta N' + \Delta N'')$, after reduction becomes

$$\frac{Mg\,\Delta N}{l}\,\frac{D^2}{r^2}\,\frac{(1+2\,\Delta/D)^2}{V_1} = V_3$$

the corrected equation required, reducing to the above case when $\Delta = 0$. The correction factor is thus $1/F = (1 + 2\Delta/D)^2$ and was computed in an auxiliary table.

It is now easy to discuss the conditions of equilibrium, for the forces X are given by the equations (second member referring to the pendulum and third member to the electrical forces)

$$X = \frac{Mg\,\Delta N}{l} = V_1 V_3\,\frac{r^2}{d^2}\,\frac{1}{(1+2\,\Delta/D)^2}$$

Hence, if $\Delta N = \Delta$, $k = 0$, the condition under which the disk just moves, without interruption, from the guard ring to the condenser plates, *i. e.*, the limiting value of the potential products, $(V_1 V_3)$ for stable positions of the disk, since

$$\frac{dX}{d\Delta} = \frac{Mg}{l} = \left(V_1 V_3\right)\frac{r^2}{D^2}\,\frac{-4\,\Delta/D}{(1+2\,\Delta/D)^3}$$

are (in electrostatic units)

$$\left(V_1 V_3\right) = \frac{Mg}{4l}\,\frac{D^2}{r^2}\,\frac{(1+2\,\Delta/D)^3}{\Delta/D}$$

Assuming $V_1 = 250$ volts, the forces X for the pendulum and the electric field were also computed.

If now, we insert the value of V_3 from the above equation and reduce

$$-6\,\Delta/D = 1 \text{ or } -\Delta = D/6$$

Hence the value of V_3 which corresponds to tangency is

$$V_3 = \frac{Mg\,D^3}{l\,V_1\,r^2}\left(-\tfrac{1}{6}\right)\left(\tfrac{2}{3}\right)^2 = \tfrac{2}{27}\,\frac{Mg\,D^3}{l\,V_1\,r^2}$$

or $V_3 = 145$ volts, above which charge the disk passes continuously from guard ring to plate.

If the suspension is provided with a horizontal micrometer by which it can be shifted as a whole from k to k' taking the needle with it, k may be eliminated. But the expression is not simple.

The idiostatic method needs a corresponding correction, and if Δ^2 is neglected in comparison with D,

$$\frac{2\,Mg\,D^2}{l\,r^2}\,\Delta N = V_3^2\left(1+4\,\Delta/D\right)$$

As the new factor is practically k or constant, V_3^2 is linear with ΔN. If, as above indicated, the suspension is provided

with a horizontal micrometer by which it can be shifted as a whole from k to k^1 taking the needle with it, k may be eliminated.

The equation may be written in terms of the two forces X (gravitational and electric)

$$X=\frac{Mg\,\Delta\,N}{l}=\frac{4\,r^2}{D^2}\,V_1^2\frac{\Delta/D}{(1-4\,\Delta^2/D^2)}=\frac{4\,V_1^2\,r^2}{D^2}\,F^1$$

A table was computed for F^1 and the two forces X may be found at once. Again, the condition may be practically stated, inasmuch as the values $dX/d\Delta$ may be easily derived. They are for the pendulum Mg/l and for the electric field

$$\frac{d\,X}{d\,\Delta}=\frac{4\,V_1^2\,r^2}{D^3}\,\frac{1+12\,\Delta^2/D^2}{1-4\,\Delta^2/D^2}$$

Equating them, we derive the voltage of transition to be characterized by (V_1), as

$$\left(V_1\right)^2=\frac{Mg\,D^3}{4\,l\,r^2}$$

since $\Delta = 0$ at the origin. Hence above (V_1) the disk would move on any slight disturbance without interruption from the guard ring, $\Delta = 0$, to either plate of the condenser; but within (V_1) the apparatus is available for accurate measurement of V_1, if k is equal to zero by trial.

8. *Experiments. Cylindrical electrometer; movable cylinder within.*—Tests of the apparatus described were begun by using a rather heavy cylinder of aluminum, damped with a vane submerged in a cup of oil. The cylinder itself weighed but 6·546 grams; but air damping was quite inadequate, though the cylinder might easily have been etched to a more appropriate degree of thinness in acid.

It is therefore necessary to make use of paper cylinders, even if the possibility of securing more nearly accurate values of the diameter of cylinder is the advantage of the metallic appurtenance.

No trouble was encountered in using a light plane mirror about 1/4 inch in diameter, with axes for adjustment in a bit of cork. To sharpen the ellipses the (yellow) image at the movable mirror should be screened off, leaving the blue image and but two superposed spectra.

Light gilt paper cylinders, weighing with mirror, etc., only about a gram, were therefore installed. An example (Table 1 and fig. 3 *a* and *b*) of the many results obtained can only be given here, M being the mass and r the radius of the movable cylinder, and R the radius of the fixed cylinder.

TABLE I.

Cylindrical electrometer; movable cylinder within.

I.—$M = 1{\cdot}105$ g.; $R = 2{\cdot}07$ cm.; $r = 1{\cdot}7$ cm.; $l = 21$ cm.; $V_2 = V_3 = 0$.

$10^3\Delta N$	V_3	Voltmeter
·08	15	15
·25	28	29
·60	43	41
1·12	60	61
1·87	77	81

II.—$M = 1{\cdot}189$ g.; $R = 2{\cdot}07$ cm.; $r = 1{\cdot}90$ cm.; $l = 21$ cm.; $V_2 = 0$; $V_1 = 250$ volts.

$10^3\Delta N$	V_3	Voltmeter
1·74	6·1	5
2·17	7·6	7
3·31	11·6	11·5
4·53	16·0	15
5·85	20·6	19

FIG. 3.

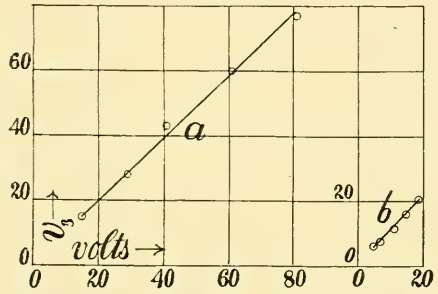

FIG. 3. Electrometer data compared with actual voltages.

The observations with the needle charged at 250 volts show the maximum sensitiveness obtained with short suspensions. These results and those by the idiostatic method are quite satisfactory and the differences are more liable to be sought for in the voltmeter with which the comparison was made than in the electrometer. It indicates the sufficiency of the equation assumed, apart from correction for the end of the cylinder, so that the latter cannot be menacing.

In addition to these experiments, a long suspension ($l = 150$ centimeters) in which the sensitiveness would have been increased 7 times or equivalent to 5×10^{-3} centimeter per volt or ·006 volt per vanishing ring was installed. The ellipses were easily found but they were continually in motion, owing to the friction of air currents moving across the wires. To make the adjustment available it would have been necessary to build a closed case around the bifilar suspension over 1·5

meters in height. It was not thought worth while to do this, and further experiments were abandoned.

9. *Cylindrical electrometer; movable cylinder within. Summary.*—The above experiments were made in the midst of the turmoil of a large city and near the engineering laboratories of a University. It is rather remarkable, therefore, that the ellipses were so easily found throughout and so easily made use of; but it was quite out of question to use the evanescence of rings by which the sensitiveness could have been increased over twenty fold. Though the work was carefully done, it is intended merely to exhibit the general character of the method, inasmuch as the storage battery which was drawn upon was unavoidably in use elsewhere in the laboratory and the potential may have fluctuated.

The design of the apparatus with a movable inside cylinder is probably the least interesting of those used. Thus it is difficult to keep a paper cylinder quite smooth or to give it a rigorous cylindrical shape and the correction for the ends can scarcely be estimated. For high charges any asymmetry of the movable cylinder is liable to place it in contact with the fixed cylinders. Thus there is a limit of sensitiveness from a purely instrumental point of view, not contemplated in theory. In the above experiments with short suspension (21 centimeters) $\cdot 7 \times 10^{-4}$ centimeter per volt was the largest double displacement practically obtained, which would mean about ·04 volt per vanishing ring. With the long suspension ·006 volt per ring may be estimated. It is far short of the theoretical datum of §4.

10. *Cylindrical electrometer; movable cylinder without.*—After a few preliminary experiments with the metal cylinder of aluminum, the gilt paper cylinder was tried and was at once successful. The mirror was attached to the paper wing needed for damping by the aid of a bent piece of thin steel wire, cemented on so as to give a horizontal axis on passing through the perforation of the bit of cork holding the mirror. For a vertical axis the whole apparatus is rotated (cf. figs. 1 and 2). The results are given in Table 2 and fig. 4*a*.

TABLE II.

Cylindrical electrometer; movable cylinder (gilt paper) without.

I.—$M = 2{\cdot}075$ g.; $R = 1{\cdot}75$ cm.; $r = 1{\cdot}59$ cm.; $l = 21$ cm.; $V_1 = 250$ volts.

Drum	$10^3 \Delta N$	V_3	Voltmeter
11·2	2·79	18·7	18
22·9	5·72	38·2	38
35·3	8·83	59·1	58
27·6	6·90	46·1	48

II.—$M = 1{\cdot}0930$ grams.

Drum	$10^3\Delta N$	V_3	Voltmeter
24·9	6·22	21·9	21
47·3	11·82	41·6	41

FIG. 4.

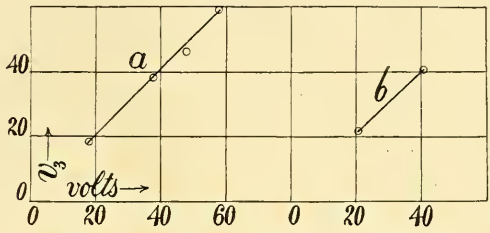

FIG. 4. Electrometer data compared with actual voltages.

The differences in this table are more liable to be of the voltmeter than of the electrometer. The needle easily carried a potential of $V_1 = 250$ volts. With $V_3 = 100$ volts, the needle became asymmetric and observations could no longer be taken. The sensitiveness is about ·0003 centimeter of double displacement per volt for the short suspension, so that ·1 volt per ring is the equivalent datum. The present form is thus easily made as sensitive as the preceding form, besides being much simpler in general design and installation.

The experiment was now pushed a step further in the direction of sensitiveness by using an even lighter paper cylinder with paper wings, the needle having the constants given in the second series of Table 2 and fig. 4*b*. The sensitiveness is now about ·0006 centimeter of double displacement per volt, twice that of the preceding case as it should be. This apparatus did not, however, behave as satisfactorily as the other, there being greater tendency of the movable cylinder to cling to the stable parts, whenever V_1 was high. In case of smaller potentials or of the idiostatic method there would be no difficulty in this respect. No doubt, if greater time and patience were spent on the work (a cylinder of celluloid suggests itself) the final result could be somewhat improved; but the limit found (6×10^{-4} centimeter or 20 rings per volt) will not easily be exceeded in practice.

11. *Disk electrometer. Apparatus and experiments.*—The disk electrometer deserves special attention because it is simpler in design and practically more sensitive than the cylinder types. At the same time, however, it is more treacherous and without special precautions there is danger of short-circuiting the highly charged disk, while the sensitiveness is enormously variable in response to any unsymmetrical position

of the disk. The instrument used is shown in figs. 5 and 6, in sectional side and front elevation. V_1 is the charged disk on the bifilar suspension of very thin copper wire yy^1, ·007 centimeter in diameter. The disk is made of thin mica, silver-plated, carried by the horizontal axial steel rod *dd*, and surrounded by the guard ring of very thin copper V_1^1. Parallel to the disk and equidistant (d) from it are the plates V_3 and V_2 of the condenser at a distance D apart, so that D is twice d. The plate V_2 is earthed and firmly held on the arm of the interferometer. The plates V_3 and V_2 are spaced at three points

Fig. 5.

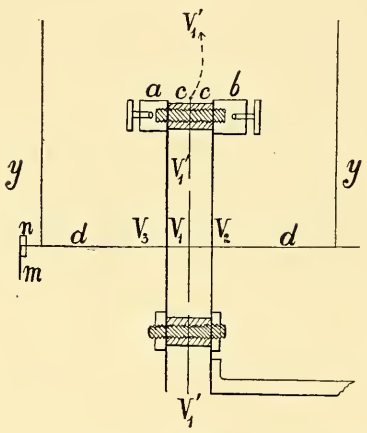

Fig. 6.

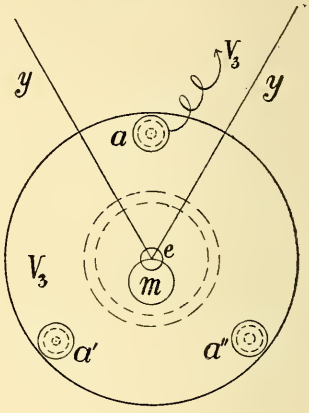

Fig. 5. Disk electrometer, vertical section. Front view.
Fig. 6. Disk electrometer, vertical section. Side view.

by hard rubber gaskets, *cc*, through the holes of which hard rubber screws are passed, the plates being ultimately secured by nuts a, a^1, and a^{11}, on the outside of the plates. The nuts a terminate in clamp screws. The guard ring V_1^1 and the suspension wires yy^1 are in metallic connection at the tops of the suspension, the latter being the same already shown in figs. 1 and 2. The small mirror, m, is attached to a small plate of cork, n, which is slotted parallel to the rod *dd*, the latter being clutched by the jaws of cork which make up the sides of the slot. In this way m may be rotated around a horizontal axis, while the apparatus as a whole may be revolved about a vertical axis.

If the grating is capable of being raised or lowered, it is not difficult to adjust the apparatus and find the ellipses. The damping of the disk is naturally good, though it may be improved by surrounding it with the case shown in fig. 1.

12. *Experiments with the disk electrometer.*—The experiments were begun with but a small distance, D, between the plates of the electrometer. In such a case the disk can not carry very high potential before it is drawn across to the condenser plates and short circuited. In fact, though the mica disks may be made very light, the annoyance of short-circuiting is correspondingly increased and the great advantage of sensitiveness cannot for this reason be realized unless the idiostatic method is used.

The disk was charged with the storage battery to 101 volts and a number of small potentials measured at the plates. The computed and uncorrected results were about 3 times as large as the true voltages. The sensitiveness is here surprisingly large, almost 8 drum parts or 2×10^{-3} centimeter per volt, *i.e.*, 70 rings per volt. The distribution of results is, nevertheless, linear and proportional to the true voltages. To account for this result by aid of the equation

$$V_3 = \frac{Mg\,\Delta N}{l\,V_1}\,\frac{D^2}{r^2}\left(1-2\,\Delta/D\right)^2$$

is not impossible, if the asymmetry is such as to make the terms in Δ/D essentially negative. Yet in the case of a large value of Δ the results are so lacking in probability that a want of uniformity or variation in the field is more liable to be in question.

On spacing the plates further, $D=1{\cdot}04$ centimeters, and carefully adjusting the disk, it carried a charge equivalent to $V_1=250$ volts easily, so long as V_3 did not exceed about 20 volts.

A new and lighter disk was thereupon introduced, weighing but ·607 gram. As it failed to carry a charge quite as large as $V_1=250$ volts, the only available smaller one, $V_1=104{\cdot}5$ volts, was given to it. The uncorrected results for V_3 are here much nearer the true values, *i. e.*, about 1·2 times too large, than were those of the preceding case, so that the correction for asymmetry is probably applicable. The mean trend of the locus is through zero. Sensitiveness is naturally much lower than above, showing $\Delta N = 5\times10^{-4}$ centimeter per volt. The experiment indicates well how markedly dependent the constants of the instrument are on the position of the disk.

The same disk was now weighted with a rider, making the total mass 1·086 grams, with the object of charging it to 250 volts. The uncorrected results, while maintaining proportionality, were about 2 times too large.

The data obtained idiostatically, however, where the deflections are essentially small, fig. 7*a*, show an excellent agreement with the true voltages. Discrepancies are as liable to be

in the voltmeter as in the electrometer. The values of k given for this table show how nearly a true condition of symmetry was attained, as its mean value from the equation

$$V_3^2 = \frac{2\,Mg\,D^2}{l\,r^2}\,\Delta N\left(1-2\frac{\Delta}{D}\right)^2$$

is but $-\cdot 0085$ centimeter.

The data, as a whole, illustrate the peculiarities of the disk method very well, giving evidence both of its relatively great

Fig. 7.

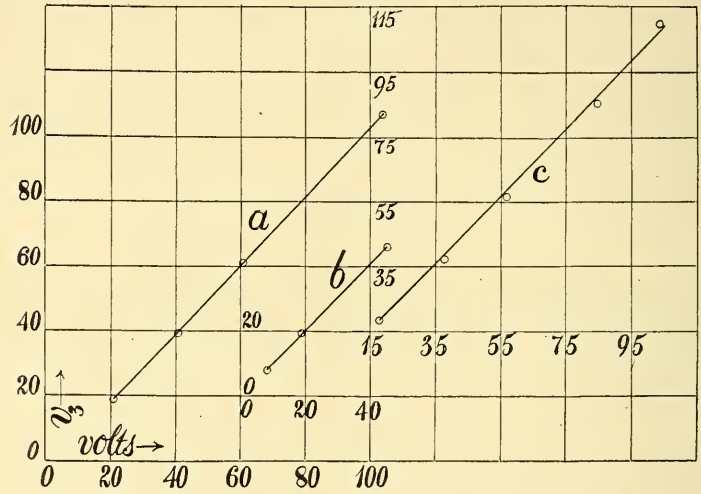

Fig. 7. Electrometer data compared with actual voltages.

sensitiveness (the double displacements being even 2×10^{-3} centimeter per volt) on the one hand, and the variation of sensitiveness as the result of a more or less unsymmetric position of the disk on the other. The ratio of observed and actual voltages is fairly constant. The question then arises as to the degree to which the latter difference may be corrected. There is, in many cases, a peculiar shift of the zero of displacement for the uncharged apparatus which is not easily accounted for; though, from another point of view, it is truly astonishing that a suspended disk should adjust itself to a given position with an accuracy comparable with the wave length of light. In the experiments detailed, such difficulties were eliminated by taking mean results, but usually the position in question was actually stable. If the shortcomings can be overcome, the practical limits of the apparatus as here constructed should, for short suspension (23 centimeters), be about $\cdot 015$ volt per vanishing ring.

13. *The Same. Further experiments.* The interesting feature of the preceding result is the large range of variability in the sensitiveness of the apparatus. It was therefore thought worth while to throw further light upon the investigation by purposely tipping the apparatus, in order that the disk might lie on one side or the other of the guard ring.

The approximate equation for k/Δ $N = \dfrac{MgD^3}{4l\,r^2\,V_1^2} - 1$ applied to the experiments did not give results quite as consistent as was anticipated, inasmuch as the same value of k did not reappear when the apparatus was tipped back apparently to its original position. Moreover, the central position did not clearly correspond to $k=0$. Hence it seems that $k=0$ is determined by the geometry of a non-uniform field. Neither did the values of V_3 correspond very closely to the values of k. The apparatus is more sensitive when the disk V_1 is on the side of the plate V_3 and about equally so when central or when on the side $V_2 = 0$.

In other experiments the disk was weighted with a rider and a similar series of data was taken, although $V_1 = 250$ volts was carried by the disk only in cases where its position was nearly central. This was even the case on adding heavier riders. The computed values of V_3 were in all cases 2 or 3 times the true values, though the proportionality is maintained. The conditions are thus too complicated for consideration here.

14. *Case of the enclosed disk.* With the object of obtaining a more uniform field, the electrometer was now modified by surrounding the disk with a short cylindric or drum-shaped tube within the guard ring. The plates and the drum guard ring are spaced, as before, by three hard rubber rings, with a hard rubber screw passed through the perforations.

Experiments were begun with the light disk, $M = \cdot 607$ gram, which was charged to 110 volts, as it would not carry an appreciably higher voltage. Consequently the rider was thereafter added, making $M = 1\cdot 086$ grams, and the disk charged as far as 250 volts. The results are given in fig. 7 *b*. These voltages, though obtained under very different conditions, are practically coincident and the discrepancies are as liable to be in one instrument (voltmeter) as the other. The remaining experiments were of the same nature.

To summarize; the enormous variation of the sensitiveness of the disk electrometers as depending upon the position of the disk, k, has, therefore, failed of interpretation; *i. e.*, the correction for V_3 does not seem to follow the above equations. The field is, therefore, probably far from uniform, possibly consisting of a conical tube of force between plate and disk on the side toward which the disk leans and of a more nearly

cylindric tube on the opposite side, where the tube must pass through the circular perforation in the guard ring. The result is an empiric instrument in which the deflections are proportional to the voltages to be measured, of increased sensitiveness, even 2×10^{-3} centimeter per volt, but not yet sensitive enough to be immediately valuable for refined practical purposes. The idiostatic instrument, for voltages above 20 volts (after the disk has been adjusted for $k = 0$ by comparing the positions of the charged and uncharged disk) may in some cases be useful.

15. *Case of the unsymmetric disk.* The cause of the departure from linearity in the preceding experiments is to be referred to a slight asymmetry in the disk, whereby an effect varying as the square of voltage of the disk is superimposed on an effect varying as its first power. To eliminate the non-linear term, it should be sufficient to obtain no deflection in the case of earthed plates, when the needle is successively charged and uncharged. In fact, the charged non-symmetrical needle between earthed plates introduces an interesting method of electrometry as follows:

Let k be the amount of non-symmetry for a disk whose mean distance from the plates D centimeters apart would be $d = D/2$. Hence for any displacement ΔN the distance of the disk from one condenser plate will be $d = D/2 + (k + \Delta N)$ and from the other plate, $D - d = D/2 - (k + \Delta N)$. Hence the displacement force is (after reduction)

$$X = \frac{V_1^2 r^2}{2} \frac{k + \Delta N}{D/2} \frac{1}{D^2/4 - (k + \Delta N)^2} = \frac{Mg \Delta N}{l}$$

As $(k + \Delta N)^2$ may usually be neglected in comparison with $D^2/4$, the equation becomes

$$V_1^2 = \frac{MgD^2}{4l r^2} \frac{\Delta N}{k + \Delta N}$$

If k is large as compared with ΔN, which will usually be the case, V_1^2 will vary linearly with ΔN.

To use this method, k must, therefore, be known, and it may be determined with the aid of a given voltage preliminarily. Many experiments were made in this way, an example of results being given in fig. 7 *c*. The asymmetry of the disk was about ·5 millimeter, and the plates were over 6 millimeters apart. The equation employed answers the requirements as closely as the observations could be made. At high voltages (100 volts) there is liable to be divergence, while at low voltages the displacement ΔN is too small for accurate work, seeing that the underlying equation is quadratic.

An apparatus like the present, intended for actual measurements, should be provided with a micrometer suspension for

shifting the disk as a whole in the direction of its axis and with more elaborate means for sighting with a view to horizontal and vertical parallelism of the disk with the plates of the condenser than was the case with the improvised apparatus here treated. It has been stated that it is an inversion of the present displacement which is superimposed on the displacement in case of a permanently charged needle, and which thus demands an apparatus tested for absence of non-symmetry, if the voltages are to be proportional to the displacements.

16. *Displacement Interferometry Applied to the Quadrant Electrometer.*—The method of measuring small angles given elsewhere may be made use of in measuring very small voltages or small increments of potential, by attaching a pair of light mirrors, symmetrically and parallel, to the needle of a quadrant electrometer. In the present experiments this was an improvised instrument, constructed by myself, the quadrants being of sheet copper fitted and soldered together and supported on cylinders of hard rubber. The bottom of the stem of the needle was submerged in sulphuric acid as in Kelvin's instrument and the suspension was bifilar. The insulation was throughout excellent. The needle was kept charged to about 150 volts with a Zamboni pile, any variation of charge being indicated by Elster and Geitel's electroscope.

In fig. 8, qq' shows a pair of quadrants in vertical section, E the needle on the stem ss', the lower end of which is platinum, bent as shown, thus making a clip to hold the light mica vane v (if necessary) submerged in sulphuric acid of the vessel c charged by the Zamboni pile. RR are the hard rubber supports of the quadrants. At a suitable distance below them the light parallel mirrors m and n (less than 1 centimeter in diameter each) are supported by the light cross piece of hard rubber rr attached to the stem ss' of the needle. The axial line of the needle E is parallel to the line rr between the mirrors and the latter are placed at a horizontal angle of about 45° to rr.

To adjust m and n to adequate parallelism, each is supported by an attached fine needle, fitting snugly in a vertical groove in the ends of rr. The needle, as a whole, is to be clamped at rr in a suitable support and sunlight is to be used. When the horizontal beam reflected from m to n and thence to a distant white screen falls within the direct shadow of n, the needles are fixed in place by resinous cement. The mirrors should be equally high.

The quadrant electrometer with the needle in position was now placed, with the aid of three long foot screws, on a circular platform just below the iron arm holding the fixed interferometer mirror M, and the reflection took place as shown in fig. 9. In effect the arc light from a collimator reflected from

the front face of the grating (blue image due to scattering) is next reflected at n, thence to m, whence it goes to N and returns by the same route, passing however from n through the grating to the observer's telescope. The case surrounding the electrometer must, therefore, be provided with a front and rear window. With so many reflections (altogether ten, including the one at the grating and the effect of the two windows) this beam is considerably weakened, and it is advisable to use black glass and not a silver mirror at the micrometer M. It is preferable, moreover, to use the glass side of the mirrors at m and n, as the silvering is liable to be brighter in the rear and the effect of thin glass plate is of no consequence. This,

FIG. 8.

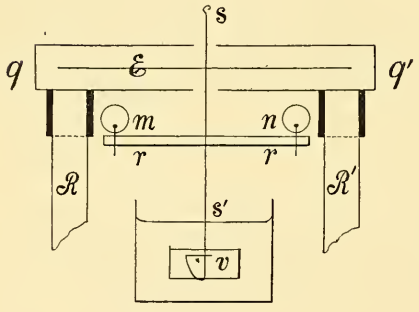

FIG. 9.

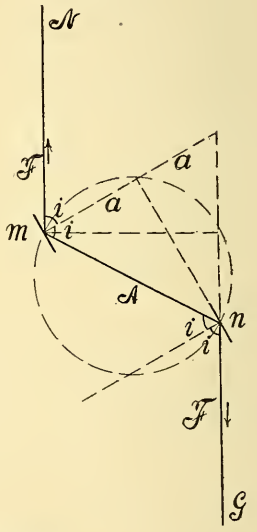

FIG. 8. Quadrant electrometer with parallel mirrors.
FIG. 9. Diagram showing direction of rays, quadrant electrometer.

in fact, was the greatest difficulty encountered, as the mirrors m and n were not at first adequately silvered and polished. Even when the direct image of the slit is clear the spectrum is apt to be dull and the ellipses are hard to find.

The adjustments, when so many conditions have to be met, were not at first easy of attainment. The electrical installation should first be completed and the needle in place between the quadrants, the electrometer being placed so that the beam from the interferometer strikes n (see figs. 8 and 9). A white screen behind n, catching the light passing beyond the edges and showing the shadow of n, facilitates this adjustment, the

slit being opened wide. The electrometer is now rotated as a whole around the vertical, until the light reflected from n strikes m and a similar screen behind the latter in the line mn is necessary here. Next, the mirror N is adjusted to normality, a white screen behind m in the direction Nm being essential, whereupon the light is reflected from n again toward the grating. As the pencil must pass through the grating G again, this is mounted to be capable of being raised or lowered and rotated around the vertical and horizontal (adjustment screws); but these are the usual adjustments on the interferometer. It follows that the electrometer must also be capable of being raised and lowered on its long foot screws, as already indicated.

Moreover, the spectrum should be so placed by raising and lowering the source of light and including the grating together with N that the higher orders of direct spectra are not in the same plane with the spectra superposed for interference. When the adjustments described are well made, there is no further difficulty in finding the solitary ellipses. As there is compensation owing to the two glass plate windows in the case of the electrometer, the ellipses are liable to be enormous, practically vertical straight lines, which are displaced with correspondingly great rapidity by the micrometer screw, and are therefore hard to find. Hence some counter compensation at the micrometer mirror is desirable, in order that centers may appear, and the displacement may be slower. A compensating plate about 1 centimeter or less in thickness, with the *vertical* focus of the light from the slit on the stationary mirror, produces very clear and sharp ellipses, admirably adapted for measurement.

17. *Observations.*—The stems of the mirrors m and n on rr were about $a = 4{\cdot}5$ centimeters apart. Hence, since $i = 45°$, $a = 4{\cdot}5/\sqrt{2}$ and if δ is the path difference $\frac{d\,\delta}{d\,\mathrm{i}} = {\cdot}0175 \times 2a \sin i = {\cdot}079$ cm. per degree. Supposing that 1 volt gave a deflection of 45° and that 10^{-4} centimeters are measurable at the micrometer, the micrometer sensitiveness should be $10^{-4}/45 \times {\cdot}079$, or about 3×10^{-5} volt, *i. e.*, about 10^{-5} volt per vanishing interference ring. It would thus seem probable that with a lighter needle and a more delicate suspension the possibility of measuring 10^{-6} volt would not be out of the question. The following observations show that these surmises are correct so far as the method is concerned.

The great hardship encountered in the present work was the unavoidable agitation of the laboratory, and this unfortunately is insuperable. After the ellipses were found they were always in motion, so that the displacement work was bound to

be rough and the use of interference rings out of the question. As the rings, however, may easily be obtained and used under suitable conditions, and as the purpose of the present paper is merely to test the method, the annoyances in question are of less consequence.

To obtain small potentials, a thin bare German silver wire about 1 meter long was stretched and insulated on a board and the ends supplied with a constant potential difference of one volt. Two points of the wire, one or more centimeters apart, were then used as a source of potential, the wires from these points leading to a Mascart key, which suitably earths and commutates the charged wires leading to the electrometer. A thermo-couple might have been used; but the long wire is preferable because of its simplicity.

In the first experiments made, the suspension was a bifilar about 10 centimeters long (each strand of several silk fibers) and about ·5 to 1 millimeter apart. No doubt the torsional stress of the fiber was here of an order commensurate with the bifilar force. The needle, being damped in concentrated sulphuric acid, moved very slowly and about two minutes were allowed for each deflection. It was thus possible to follow the ellipses on commutation, from one to the other extreme elongation, by moving the micrometer screw proportionally to the displacement of ellipses. As a rule, the ellipses were quite clear all the way, showing that the adjustment for parallelism of mirrors on the needle by the aid of sunlight is adequate. The potential of the charge on the needle was of the order of 150 volts.

In the first experiments, $\Delta N/\Delta V = \cdot 57$ centimeter was the displacement on the micrometer per volt, so that $\Delta N = 10^{-4}$ centimeter corresponds to ·000170 volt, or the sensitiveness is about ·000060 volt per vanishing interference ring.

The instrument was now improved by inserting a longer bifilar suspension, consisting of a single fiber of silk. The damper and other details were retained. The potentials were tapped from points of the long wire, respectively 5 and 10 centimeters apart. Owing to the very large deflection, the ellipses were not equally clear throughout the whole displacement from elongation to elongation.

The instrument behaved much better in the present case and the sensitiveness had been much increased, particularly in the later series of observations. Since $\Delta N/\Delta V$ was of the order of 2·9 centimeters per volt, 10^{-4} centimeter corresponds to ·000035 volt, *i. e.*, to about ·000010 volt per ring, so that under favorable circumstances a few millionths of a volt should be discernible.

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Art. VII. — *The Upper Devonian Delta of the Appalachian Geosyncline;** by Joseph Barrell.

Part II. Factors Controlling the Present Limits of the Strata.

Contents.

Introduction and summary	87
Present extent and thickness of the Upper Devonian	88
Comparison of this restoration with other maps	91
Influence of erosion cycles	93
Present limits dependent upon intervening baselevels	93
Relation of post-Ordovician erosion to original limits of Devonian	95
Influence of late Paleozoic cycles of erosion	96
Degree of destruction by the pre-Newark cycle	97
The Newark erosion cycle and the quartzite conglomerates	99
The Jurassic erosion cycle	102
The post-Jurassic erosion cycles	103
Absence of structural relations between present and original limits	105

Introduction and Summary.

Toward the west and southwest the Upper Devonian delta faced the sea. The study of its strata, guided by criteria for distinguishing the modes of origin of the several formations, has led in the first part to certain conclusions. But facing the east the marginal outcrop is near the region of maximum thickness. The beveled edges of the strata, measured in thousands of feet, bear witness to a former extension toward the ancient land of Appalachia. The nature of the surface and the relations of the delta to the sea are but one half of the problem. The former extent and nature of the strata now destroyed and the relations of the delta to the old-land constitute the other half.

Although Appalachia and its marginal waste plains no longer exist, we may attack these questions by inferences from the nature of the remaining strata, from the structure of the rocks beyond, and by the evidences as to the amounts of erosion which they have suffered. Merely because the study is inferential, the results are not necessarily less secure. The commonest conclusions in geology are in fact inferential. Therefore it is not the absence of inference, rather is it the definiteness and convergence of independent lines of evidence and the soundness of the principles according to which the conclusions are inferred which determine the security of the answers. It is seen then that the principles of interpretation are as impor-

* Continued from this Journal, (4), xxxvi, pp. 429–472, 1913.

tant as the facts interpreted; but those criteria which are used by geologists to determine the original nature and limits of eroded formations are less well demonstrated and are much more vaguely employed than are those used for determining the modes of origin of strata. In the study of the existing sediments observation and demonstration are able to follow fairly close to hypothesis, but in the more difficult study of that which is no longer existent unchecked hypothesis still largely prevails. This second part of this subject is taken up, therefore, in discussing the causes which have determined the present limits of the Upper Devonian formations and the lack of relationship between the present outcrops and the former limits.

It has been customary, on paleogeographic maps, to draw the original limits of formations at no great distance beyond their present outcrops. On the other hand, areas of ancient rocks tend to become regarded, unconsciously to the thinker, as land areas through all the younger ages. To a certain degree both these principles as rules of guidance point in the direction of the truth, and it is only by following them in a general way that paleogeographic maps may be constructed. Yet in any particular problem these principles may lead to large errors. Sediments may originally have existed hundreds or thousands of feet thick and reached hundreds of miles beyond their present boundaries and now leave no trace. An extended discussion of these subjects is required in connection with the Upper Devonian, as is seen on comparing the present conclusions with those of previous writers. This part, on the relation of present outcrops to causes other than the original limits, is preparatory for the more definite evidence which follows in the third part. The preliminary discussion shows that there is no reason why the Upper Devonian sediments may not have extended northward to beyond Lake Ontario and eastward to the margin of the present coastal plain. In the third part, to be published in a following number, the indications given by the strata as to their former extension are taken up and several independent lines of evidence converge to the conclusion that the Upper Devonian did extend originally to the neighborhood of these limits.

Present Extent and Thickness of the Upper Devonian.

The map of the Appalachian geosyncline, fig. 1,* shows the limits of the Upper Devonian outcrops and the contours give approximately the total thickness of sediments which were deposited during the Upper Devonian.

* Figs. 1 to 4 inclusive are published in Part I, this Journal (4), xxxvi, pp. 429–472, 1913. Fig. 1, for convenience of reference is republished in this part also.

FIG. 1.

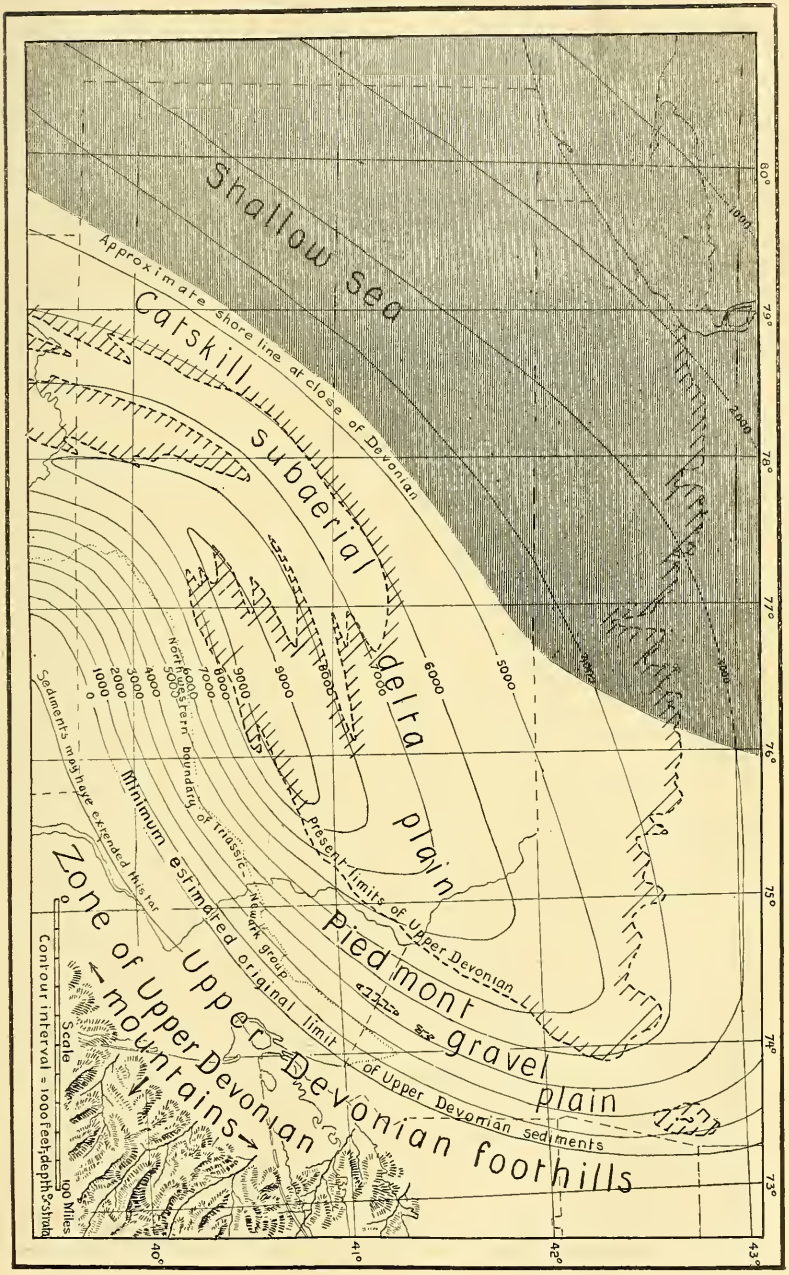

FIG. 1. The Appalachian geosyncline at the close of the Chemung–Catskill epoch.

In southern New York the strata dip gently southeast and outcrop in a broad hilly upland from 1500 to 2000 feet in elevation; the general surface however slopes north, contrary to the slope of the strata, and overlooks the central lowland of New York, lying at a general level of 400 to 500 feet, developed on the soft Ordovician and Silurian strata. The old upland surface is now trenched by deep transverse valleys leading to the north or south and giving a sinuous outline to the limiting outcrop. In eastern New York the strata are more resistant, dipping gently southwestward and extending northeastward in the Catskill Mountains until the higher peaks reach elevations in the neighborhood of 4000 feet. Close in front lie the Mohawk and Hudson Rivers near the level of the sea. The thickness of the Upper Devonian at its margin is about 2000 feet in western, about 4000 feet in eastern New York. The strata must therefore have extended at one time much farther to the north.

Facing the Appalachians the Upper Devonian as far south as Lat. 41° forms a mountainous tableland of gently flexed strata, the elevations descending from the heights of the Catskills to about 2000 feet. Immediately to the east lie the folded structures of the Appalachian system over which the Upper Devonian strata, here from 4000 to 6000 feet thick, must once have extended, participating in the folded zone. South of Lat. 41° to 41° 15′ the folded structures advance westward and involve a greater breadth of the Appalachian geosyncline. The Upper Devonian strata plunge steeply beneath the synclinorium of the anthracite coal basins, the eastern outcrop showing here maximum thicknesses of between 7000 and 9000 feet. West of this synclinorium is a broad cross anticlinorium running north and south between Long. 77° and 78°. This upwarp crosses a series of great folds, producing very zigzag outcrops in the strata pitching away from it. The Upper Devonian is completely removed across this transverse anticlinorium and exposes in its flanking outcrops a thickness decreasing northwestward to 6000 feet. On the west the isolated Broad Top Coal basin shows the Upper Devonian on all sides and offers good opportunities for measurement. The last exposure of the full thickness is on the Allegheny front, at the limit of the strongly folded structures, but the upper part outcrops in three gentle anticlines to the west and bore holes show the continuation of the strata.

In the region of folding the measurements of thickness can be made in a limited distance and with small error but transitions at base and top prevent a high degree of accuracy. Some changes of thickness due to folding are also probable. In the other regions the thicknesses are not so easy to obtain.

Over the western part of Pennsylvania the bottom of the Upper Devonian is nowhere exposed. In southern New York, on the other hand, the upper beds have been removed and detailed geologic mapping has not crossed that wide belt between the middle Devonian and the Mississippian outcrops. In northern New Jersey also the isolated Green Pond Mountain axis preserves merely a remnant whose original thickness is not known. In the neighborhood of Lake Erie, however, more exact figures are determinable. But although these difficulties prevent high accuracy, the errors are small in comparison with the total thicknesses of thousands of feet.

A striking fact in regard to the distribution of thicknesses is that they are greatest near the southeastern margin. It is to be noticed further that the boundary from Harrisburg to Lake Erie is everywhere oblique to the lines of equal thickness, decreasing from about 9000 feet in the southeast to 2000 feet in the northwest. In the region of the folded Appalachians the thicknesses range from 6000 to a little over 9000 feet. It appears therefore as if there were preserved to our geologic period but a portion of the original basin. The eastern side is almost wholly gone and on the north erosion has etched back the margin for an unknown distance. The restoration of this basin showing its original extent and the thickness and character of the strata is the task which we have set.

Comparison of this Restoration with Other Maps.

Before entering upon a detailed analysis of the problem it is desirable to see how the present restoration of the Upper Devonian as shown in fig. 1 compares with others which have been made.

J. D. Dana in 1895 published a map of North America at the commencement of the Carboniferous era.* On it the limits of the sea, and of the sediments, are shown as approximately following the north boundary of Pennsylvania, Lat. 42°, and lying close to the limiting outcrops on the southeast.

The most detailed map was published by Willis in 1899,† and is the map with which the present one should be most closely compared. The two differ materially. In Willis' map the whole area of sedimentation is indicated as a shallow sea and the north limit of the basin is drawn at Lat. 43° 15′ where the present map indicates a former thickness of between 2000 and 3000 feet of Upper Devonian strata. On the east the shore line as shown by Willis follows closely the marginal outcrops. The thicknesses taken by Willis include the Hamilton, which

* Manual of Geology, p. 633.

† Maryland Geol. Surv., vol. iv, pl. vii. Geography of the Eastern United States During and at the Close of the Devonian Period.

is here excluded, and the present map rests in part upon publications by the United States and New York Surveys issued since the map by Willis was published. A large difference is, however, owing to another cause. In Lycoming County, in North Central Pennsylvania, Willis takes data from Andrew Sherwood* for the thicknesses of the Upper Devonian. But these are measurements of partial and not complete sections. Their use gave an apparent lack of sedimentation and consequent constriction of the geosyncline. The present map in that region has been controlled by the very complete section measured by H. M. Chance.† But it is in the location of the margins of the basin that the two maps differ most widely; the differences being the result of the application of different principles for the location of the original margins of eroded formations. Willis has crystallized these more definitely and consciously than others of the living geologists and their discussion is taken up in detail in later sections of this article. The two maps are important in showing the wide difference in results which may flow from different interpretations of the same set of facts.

In 1906 Chamberlin and Salisbury published a set of paleogeographic maps which showed distinct advances over those preceding.‡ The map for the Upper Devonian (II, p. 431) shows the northern limits of water as possibly existing to the line located by Willis. A possible extension of water on the east is shown about to the limit of sediments indicated on the present map. Continental deposits are not discriminated. A probable water body is shown as existing south of Connecticut and extending possibly northward up the Connecticut valley.

In 1910 Schuchert published his Paleogeography of North America§ which gave a wealth of detail beyond anything previously published. In the construction of his maps he followed the principle that the shores should be shown as near to the limiting outcrops as is reasonable: that is, the extension of the seas to the limits set by Schuchert is practically certain, but, as is noted by Schuchert (p. 446), this method may err on the side of too much restriction of the continental seas. Following this method in his map of the Upper Devonian (pl. 77) the shore is shown on the north where it is drawn by Willis. The Catskill Mountain area is shown as an estuary (see p. 545) separated from the sea by a barrier. The necessity of a seaway for the migration of faunas causes him to locate a strait across northern New Jersey, making the Skunnemunk con-

* Second Geol. Surv., Pa., vol. G-2, 1880.
† Second Geol. Surv., Pa., vol. F, Appendix B, 1878.
‡ Geology, Earth History, II, III.
§ Bull. Geol. Soc. Am., xx, 427–606.

glomerate marine. The beds in Pennsylvania are shown as wholly marine and advancing east somewhat farther than indicated on previous maps.

The present map, fig. 1, shows the shore line at the close of the Devonian farther west than any previous map but the margin of the sediments farther east, except for the New Jersey strait of Schuchert which is here eliminated. Between the two limits is shown, not a shallow sea or estuary but a subaërial delta plain. The comparison with the previous maps crystallizes the differences between them and introduces the need for a discussion of the principles which have controlled the past and the present restoration.

Influence of Erosion Cycles.

Present Limits Dependent upon Intervening Baselevels.

The original development of a formation was dependent upon the baselevel of the time, the initial baselevel in its history. At a distance from the shore the inland baselevel determining the relations of erosion and continental sedimentation are controlled by the river grades and may depart appreciably from sea level. The limits of deposition, however, are limited in the initial cycle to the parts below baselevel even if somewhat above sea level.

In the drawing of the earlier paleogeographic maps the views prevalent in the middle of the last century determined the principles of construction. It was originally assumed that the present limits of a formation are controlled by but two baselevels of erosion, the initial one, giving the original limits of sedimentation, thought of as necessarily a shore line ; and the present cycle, giving the existing relief to the land. The idea of clearly separated baselevels was not however present in theory. Uplift was looked upon as progressive, the successive shore lines forming on the whole a descending series. It apparently was not thought that any part of the continental surface save the anticlines of folded regions had lost very much in elevation. No quantitative comparison had been made between the great volumes of the sediments and the enormous denudation which they imply. Consequently the old shore lines were located by filling up in imagination the river valleys and extending the strata to the higher upland levels of the region. It was not believed that extensive overlaps or outliers could have existed, for it was thought such could not have been wholly eroded. This blended two-cycle principle, inherited from the past, still unconsciously controls the work of many geologists whose specialty does not lie in the application of present physiographic knowledge to the distant past.

In the past two decades has grown up an increasing appreciation of the complexity of erosion cycles. Davis early recognized one baselevel as the floor of the Triassic formation and another as the surface truncating the higher ridges of Pennsylvania. The latter he correlated with the floor at the base of the Potomac group and therefore it was placed by him as of Cretaceous date. Another erosion level, existing in the valleys and beveling the softer formations, he placed as of Tertiary age. Since then still other minor cycles have been added.

What effect should this development of the erosion theory have upon the problem of Paleozoic geography? Its influence may be considered by introducing first the effect of the Cretaceous baseleveling. In that Jurassic-Cretaceous cycle it has been held that all of eastern North America except certain residual mountain groups was reduced to a peneplain. Consequently if ancient strata, for example those of the Devonian age, were warped upward at the close of the Paleozoic above the level of the Cretaceous peneplain, no matter how far they originally extended, so long as they did not enter into the residuals still remaining upon that plain, they would have become completely destroyed. Even if they had extended outwards for hundreds or thousands of miles at elevations above that level, now no vestige would remain. Consequently the extension of the strata to the present level of the uplands would only restore the boundaries as they existed in the Cretaceous, not in their time of origin. This may be called an interpretation of paleogeography with respect to a three-cycle basis, the Triassic and Tertiary cycles being looked upon by most writers as relatively partial and local.

Chamberlin and Salisbury in their Geology and Willis in his Outlines of Geologic History have recognized the pertinency of this principle by showing a probable extension of the early Paleozoic seas upon the Canadian shield where now only pre-Cambrian rocks exist below the Cretaceous level. Such relations of intervening erosion cycles to the problem of the ancient boundaries does not however appear to have been clearly formulated. A paper in which is stated distinctly the relation of the Cretaceous cycle to an earlier problem, here the problem of Permian folding, is that by R. T. Chamberlin on the Appalachian Folds of Pennsylvania.* Here the Cretaceous baselevel is definitely assumed to be essentially the same as the post-Permian baselevel.†

It is the conclusion of the present writer, however, that many erosion cycles, developed with respect to successive baselevels, have intervened between the Devonian and the present and that the Cretaceous cycle is a broad term for a number of

* Jour. Geol., xviii, 228–251, 1910. † Loc. cit., 237–241.

partial cycles extending from the close of the Jurassic into the early Tertiary.* If this be so, it still further destroys any real relationship between the limits of the present outcrops and the original limits of sedimentation, even in cases where residuals still rise above the upwarped Cretaceous baselevel.

Relation of Post-Ordovician Erosion to Original Limits of Devonian.

A more or less widespread crust movement took place at the end of the Ordovician. Uplift and folding occurred over the Appalachians as far west as the eastern side of the Great Valley, as is shown by the unconformity at the base of the Silurian and the fact that fragments of Ordovician formations enter into the Silurian basal conglomerate. This has been called the Taconic revolution from the region where the significance of the unconformity was first recognized. The Taconic and Green Mountains still stand in Vermont at elevations in the neighborhood of 4000 feet. The question arises,—how much of the metamorphism and folding of that region should be ascribed to the close of the Ordovician, how much to later movements? Their elevations, high above the Cretaceous baselevel, have been commonly looked upon as an inheritance from the Silurian. Did they contribute waste to the Devonian sediments and form a barrier in Devonian times, or were the Silurian mountains already leveled before the Middle Devonian so that the Devonian waste had to come from farther regions and may possibly have mantled the beveled folds?

The plateau outlier of the Rensselaer Grit, shown in fig. 1, goes far toward supplying an answer. In the first part of this article this formation has been described and reasons advanced for holding that it is more probably of Middle Devonian age, though it was assigned by the older geologists to the Silurian and by J. M. Clarke to the Upper Devonian. The grit rests unconformably upon the Upper Ordovician schist and lies immediately west of the Taconic range. The latter is composed of these same schists and rises a thousand feet above the surface of the plateau. The Rensselaer formation contains beds of slate, others of grit, and still others of conglomerate. Feldspar, gneiss, and quartzite pebbles are abundant. The material of the plateau shows therefore that it was not largely derived from the schists of the Taconic range which now overshadows it. Furthermore the Rensselaer grit is itself folded and metamorphosed, indicating that it has once been somewhat deeply buried and while so buried subjected to powerful earth

*See Abstract, "The Piedmont Terraces of the northern Appalachians," Bull. Geol. Soc. Am., 1913. Paper read Dec. 30, 1912.

pressures and high temperatures. It is, however, on the western margin of these orogenic activities. These relations of attitude, of composition, and of internal structure show that the present Taconic region was lowlying in the Devonian, no longer a mountain barrier, and that a large part of the strong folding, thrusting, and metamorphism which now mark the Taconic and Green Mountain region was imposed after the Rensselaer grit was deposited, probably in the closing revolution of the Paleozoic.

In New Jersey also the Green Pond Conglomerate of Silurian age rests unconformably upon Ordovician limestone and pre-Cambrian gneiss. Its pebbles, except at the immediate base, are water-worn pebbles of white quartz and not local accumulations from an unreduced region. Much erosion had taken place between the close of the Ordovician and the beginning of Silurian deposition.

Further, Lower Devonian quartzites and fossiliferous limestones are found immediately east of the Green Mountains in northern Massachusetts over a region doubtless affected by the Taconic folding. Clearly then we must conclude that the mountains of the Taconic Revolution did not endure to supply the Upper Devonian sediments. They no longer rose as insuperable barriers and the sediments were more or less free to transgress their eroded structures.

Influence of Late Paleozoic Cycles of Erosion.

Here will be considered from the standpoint of theory the possible effects of the erosion cycles which followed the deposition of the Upper Devonian but preceded the Permian folding.

The original marginal parts of a formation are the least downwarped. They may, in fact, if terrestial in origin, have accumulated at considerable elevations above sea level. Even if not originally above sea level a slight upwarp of the margins of the basin might completely destroy them when the central and thicker parts would still remain. While a deposit exists as an unconsolidated surface formation it is particularly sensitive to even minor changes of level. The most widely extended formations are the ones least protected by overlying materials and most constantly subjected to erosion through later time, so that, as Gilbert has pointed out, the evidence of the greatest past transgressions of the sea becomes most completely obliterated.* After such an erosion of marginal strata let the sea again invade the land and a disconformity is the result, in which the time interval marked by the hiatus represents some-

* Continental Problems, Geol. Soc. Am. Bull., iv, 187–190, 1893.

thing more than the time in which sedimentation has been absent.

For the Upper Devonian marginal sediments the problem is somewhat different. A great mantle of terrestrial deposits extended toward the mountains. The river grades which determined whether erosion or deposition should take place must have been subject often to minor disturbances of a climatic or diastrophic nature. The disconformities produced have been destroyed along with the marginal strata, but each pulse of erosion on the margin of the plain must have been recorded by a pulse of deposition of coarser waste toward the center of the basin. Climatic and diastrophic movements during and following the Upper Devonian would thus tend to affect the margin and the center of the basin in different ways. The relation between the two will, however, be treated more fully in a later part of the paper.

Degree of Destruction by the pre-Newark Cycle.

The next related problem turning upon ancient baselevels deals with the erosion of the early Mesozoic. Sedimentation began about the middle of the Triassic in certain tracts of the Appalachians; giving rise to the red conglomerates, sandstones and shales of the Newark group. These sediments rest upon floors which had been intensely folded and metamorphosed near the close of the Paleozoic, as shown by the Carboniferous strata which are involved in the Maritime Provinces of Canada and in Eastern New England. Further, near the Susquehanna river in Pennsylvania the Triassic approaches within ten miles of intensely folded Upper Paleozoic rocks. Except in Nova Scotia the Triassic nowhere, so far as the base is visible, rests upon Devonian rocks. Does that mean that the Upper Devonian never extended over the region now occupied by the Triassic of the United States, or does it mean that sufficient erosion could have taken place after the folding of the Permian but before the deposition of the basal Newark of the mid-Triassic to have removed thousands of feet of resistant Devonian and Silurian formations?

Light on this question may be gained by an examination of the floor of the Newark rocks. Davis long since called attention to the fact that the western contact in Connecticut is such an old floor resurrected by Tertiary erosion. He notes that it is approximately a tilted plain, since the outcrops extend in a nearly straight line, except where broken by faults. It cuts across greenstone and schist and granite without notable deflection. The basal beds of the Newark are moderately fine-grained and are not the coarse agglomerates which skirt a rugged, moun-

tainous upland. The conglomerates lie mostly on the eastern side in Connecticut, prevailing especially in the higher beds, and are mostly of cobbles under a foot in diameter. They indicate the repeated rejuvenation of hills not far distant from the present eastern margin and appear to mark a zone of faulting and uplift on the east during the progress of sedimentation to the west. Thus, in a region of resistant metamorphic rocks, erosion toward an early Triassic baselevel had become largely completed. This does not mean, however, that a smooth plain was necessarily, or even probably, developed across hard rocks. Minor movements of the crust and the long time consumed by the last stages of the erosion cycle may perpetuate a hilly relief long after mountains have vanished. Irregularities in the Triassic boundary in Massachusetts suggest that a mature relief, measured by hundreds of feet, existed at the time of burial, but this is a minor feature in comparison with the erosion of thousands of feet which the metamorphic and crumpled structures of the floor imply. The floor can be studied further in Pennsylvania, on the southeast side of the Triassic. Here it is tilted 15 to 20 degrees northwestward and erosion has cut across both the Newark and the underlying formations. The floor crosses pre-Cambrian gneiss, Cambrian quartzite, and Cambro-Ordovician limestone. Although the margin is highly irregular in detail, it is seen to intersect hard and soft formations without large response to the erosive resistance of the formations. It is difficult to eliminate completely the influence of faults and determine how much of the irregularity was due to the original surface. In the Germantown quadrangle of the Philadelphia folio* the irregularities in the margin of the tilted floor suggest hills of gneiss rising to 1300 or perhaps 1700 feet above the pre-Newark valleys, but on the other hand the contact crosses the broad anticline of pre-Cambrian in the Phoenixville quadrangle for 18 miles without showing any greater deflections than this from the limestone at each end. The relief, therefore, was not due to the pre-Newark folding, but was related to the hardness of rocks largely at least independent of structure.

It seems clear, then, that the folded structures of Permian date had suffered profoundly from erosion even by the beginning of Newark deposition, and the geology of the Newark floor cannot be used as an argument to prove the absence of the Upper Devonian from those formations which were involved in the Permian folding. If they were high above baselevel they would have suffered destruction before the beginning of Newark time. Although such seems to be the conclusion, it assists in the conception of the process of rapid

* U. S. Geol. Survey.

erosion to note the fatal weakness in the structures of the Appalachian geosyncline. The three notably resistant formations, the Kittatinny, Pocono, and Pottsville formations, are separated and underlain by great thicknesses of non-resistant rocks. Wherever this series is exposed to erosion the rivers rapidly sink toward baselevel upon the soft formations and the mountain-makers become separated by deep valleys. Each is sapped from all sides. It is the old proverb—united we stand, divided we fall—applied to geology. It is not thought, from other considerations, that the Upper Devonian ever extended over the Connecticut Valley. It is concluded, however, in the following parts of this article, that, as shown in fig. 1, it once thinned out over the region now occupied by the Triassic in New Jersey and Pennsylvania, but was destroyed before the beginning of the Newark deposition. The conclusion is made more impressive by noting that on the Susquehanna River the Triassic rests on Cambro-Ordovician limestone. Only eight miles north lies the ridge of Silurian quartzite. Beginning with this formation, four miles of strata, including Devonian, Mississippian, and Pennsylvanian formations, rise vertically in the somewhat overturned arch of the syncline. The great elevations which they imply on the east, even though they rapidly thinned out in that direction, had been removed before the beginning of Newark time.

The Newark Erosion Cycle and the Quartzite Conglomerates.

The Newark group of red shales and sandstones occur in a number of isolated areas from Nova Scotia to North Carolina. The one which enters into the present discussion is the New York-Virginia area. This shows a monoclinal structure, dipping northwest at average inclinations of 15 to 20 degrees, but broken by faults. As interpreted by the present writer, the structure across the basin during sedimentation appears to have been analogous to that which exists at the present time across the Great Valley and Sierra Nevada of California. There, uplift on the east, downsinking on the west during the later Tertiary has given rise to profound erosion of the uplifted side and transfer of sediment on to the sinking floor. A fault zone separates the Great Valley, the downsunken side of the block, from the Coast Ranges. The latter contribute sediment to the valley, but the greater part comes from the crystalline rocks of the Sierras.

The northwestern boundary of the Triassic rocks is shown on the map, fig. 1. On the north it lies ten miles southeast of the Upper Devonian Skunnemunk conglomerate and thirty-three miles from the present Catskill margin. From there it trends southwestward across the structure, gradually approach-

ing to the main area of Upper Devonian until on the Susquehanna River it is only eight miles distant. Kümmel has made thorough studies of this margin as well as of the rocks of the Triassic* and shows that the margin is in large part a fault boundary, the strata dipping northwest against it. Close to the margin are numerous beds of breccia and conglomerates. The breccias are derived from the Cambro-Ordovician limestones, but the pebbles of the conglomerates are almost entirely of quartzite. Between the Delaware river and Pompton the Triassic boundary measures 65·5 miles. Of this, 49·75 miles now rest against gneisses and granites. In the marginal conglomerates, however, quartzite conglomerate covers 19·5 miles, limestone conglomerate or breccia 9·75, gneissic conglomerate but 4·00 miles.† The total thickness of the Triassic in New Jersey, Kümmel‡ places at 20,300 feet. This thickness was determined after allowing for reduplication by faults and in spite of an expectation that the thickness was much less. Even if the existence of minor faults should somewhat reduce this figure, it is evident that the group is enormously thick. The conglomerates occur at all horizons, but are extensively developed only within a few miles of the northwestern margin.

At the time that Dr. Kümmel made these studies he was inclined to believe that the breccias and conglomerates were the result of wave action, but he has since come to the opinion that the Newark series is of fluviatile origin. The writer also has studied these conglomerates at intervals since 1896.

In order to shorten the discussion and pass more quickly to the bearing on the Upper Devonian problem, the conclusions will be given without extended presentation of the evidence. The relation of the conglomerates to the present margin shows that this was the margin or the vicinity of the margin during sedimentation also. The maintenance of this margin during such a thick accumulation of sediment indicates that it was a fault boundary then as now. The limestone breccias, holding angular bowlders usually small but ranging up to twelve feet in diameter, are to be interpreted as talus and wash deposits from the immediate vicinity. The waterworn quartzite cobbles show fluviatile transportation for some miles. Their volume indicates that quartzite was the dominant rock over much of northwestern New Jersey during the Newark sedimentation. The present juxtaposition of these conglomerates against pre-Cambrian gneiss shows that in the movements of profound fracturing and tilting at the close of Newark time the old fault boundary was utilized; the northwest side moving

* Ann. Rpts. Geol. Surv. New Jersey for 1896, 1897.
† H. B. Kümmel, Ann. Report Geol. Surv. N. J. for 1896, pp. 55, 56, 1897.
‡ Ann. Rpt. Geol. Surv. N. J. for 1897, p. 59, 1898.

up with respect to the conglomerates and bringing the pre-Cambrian against them. In a few places, however, the gneisses had begun to be exposed toward the close of Newark time as shown by the gneissic conglomerates in certain of the higher beds of the Newark.

The conglomerates have been attributed by various investigators to wave origin, or even to glacial, but J. Volney Lewis regards the Newark as essentially a fluviatile formation,* and J. D. Dana came to somewhat the same conclusion.† The present writer holds the Newark formations to be fluviatile, but differs from the last two authors cited in believing that the sediments of the New Jersey area came largely from the east, from regions now submerged beneath the sea. Considerable material was of course supplied from the northwestern fault wall as shown by the quartzite conglomerates, but the gneisses and granites on that side were not then exposed to erosion and could not have been the source of the feldspathic and muscovitic debris which makes up much of the Newark rocks.

Where the Triassic floor is exposed on the northwestern side of the basin at several localities between the Hudson and Susquehanna rivers it is seen to consist of Cambro-Ordovician rocks. After many thousands of feet of deposition the northwestern wall was still dominantly mantled by Cambro-Ordovician limestone. The uplift on the northwest side of the margin during sedimentation was therefore moderate, the downthrow on the southeast side of this margin was very great. Distributive or step-faulting probably existed, rather than a single simple fault, so that farther northwest the crust may have been more elevated than against the immediate margin of the Triassic and may account for some of the overlapping relations observed in Pennsylvania.

The quartzite conglomerates seem to be clearly of fluviatile origin without indications of contributing glaciers. Wherry has recently favored the view that glaciers were the ultimate source of these bowlders,‡ but the cobbles could be moved along the bottoms of rivers such as those which now drain the Appalachians, and their counterparts could be found in those south as well as north of the recent glacial limit. They are dominantly of one character in any one exposure. The quartzite cobbles are well waterworn, but such as are subangular show commonly that the subangularity is the result of breakage and not of glacial wear. In size the bowlders aver-

* The Origin and Relations of the Newark Rocks, Ann. Report U. S. Geol. Surv. for 1906, pp. 99–129, 1907.

† Manual of Geology, 743–745, 1895.

‡ E. T. Wherry: North border relations of the Triassic in Pennsylvania, Proc. Acad. Nat. Sci. Philad., pp. 114–125, 1913.

age perhaps three to six inches in diameter but those up to 12 and 15 inches are common. Eight miles east of the Delaware the writer has noted bowlders from 24 to 30 inches in diameter. The quartzite bowlders of this locality are regarded by Wherry as of Silurian origin. No careful lithological studies have been made of those in New Jersey, however, to determine if they were derived from the Silurian or Upper Devonian formations.

The size and the degree of rounding of the quartzite conglomerates show that they have been carried by streams, but probably in most cases from regions within five, ten or fifteen miles. Many of the cobbles indicate distinctly less transportation than do the bowlders of the Upper Devonian conglomerates of New Jersey. Their volume, their persistence through the Newark sediments and their coarseness in beds high in the group show that they came from formations of great volume which were progressively elevated.

This discussion of the geology which existed during the upper Triassic throws light upon the extent at that time of the Paleozoic formations. What is now the Great Valley and much of the Archean Highlands of Northern New Jersey was mantled then by heavy formations of quartzite of which the Green Pond axis is the sole isolated remnant. The thorough cementation of this quartzite appears to show that at the end of the Paleozoic it had been covered by still higher formations, possibly by overthrust. The volume of quartzite in this region in the upper Triassic implies an earlier extension still farther eastward.

In Pennsylvania south of latitude 40° 30′, although nearer to the present outcrops of the upper Paleozoic, such a Triassic mantle of Paleozoic quartzite does not appear to have existed. It is to be inferred that the Permian folding carried it here so high that the early Triassic cycle of erosion pushed back the outcrops to near the present line of vertical emergence.

The Jurassic Erosion Cycle.

The Jurassic and later erosion cycles have served to change the areal geology from what it was during the Triassic to what it is to-day. So far as the direct application to the Upper Devonian problem is concerned, the chief effect has been to remove such outlying areas as may have connected the present outcrops in Pennsylvania and New York with those remaining in the Green Pond axis. The northern limits must also have been greatly restricted.

There is, however, an indirect reason why these post-Triassic cycles should be treated in some detail. We can perceive here

something of the magnitude of the work and the degree of completion of the later Mesozoic cycles. Thus it becomes easier to accept the results arrived at in regard to the erosion accomplished in the earlier periods. The discussion adds force to the general conclusion regarding the competency of erosion in a single geologic period to go far toward leveling mountain structures. The Newark sedimentation was brought to a close near the beginning of the Jurassic by a crustal fracturing on a large scale and a tilting of the fractured blocks; in the Connecticut area the tilting was to the east, in the New York-Virginia area to the west. The Newark strata dip at an average inclination of 15 to 20 degrees away from an axis between the two areas. It is not known to what extent the tilting extended beyond the present areas of Newark rocks. Presumably between the two graben the tilting disappeared, but in its place was a considerable upwarp, implied by the tilted structures of the two sides. The upwarp, however, was not measured simply by the amount of the tilt; since the fault movements neutralized more or less the geanticlinal structure. Nevertheless the movement was of a mountainous order since individual crust blocks are many miles wide.

By the close of the Jurassic, erosion had again reduced the mountains to a hilly country, planing across the entire thickness of the Newark sediments, across their included traps, across the resistant floor below. A tilt of 15° to the previously level floor gives an elevation of 1367 feet per mile; 20 degrees gives 1806 feet. Areas, miles in width, of granite-gneiss sloping at these inclinations were planed across in Jurassic time after the Newark sediments had been removed. Then a marginal downwarping of the continent began and the Potomac sediments of the early Comanche began to be laid down on this new floor prepared by Jurassic erosion. The floor was marked by hills one or two hundred feet in height, but this was a minor relief in comparison with that developed by block faulting and tilting which marked the beginning of the Jurassic period. This relief in the floor of the Potomac sediments is of such an order as may have been due to minor fluctations in the baselevel, late in the cycle of erosion.

The Post-Jurassic Erosion Cycles.

In discussing the post-Triassic erosion of the Appalachians, commonly no distinction has been drawn between Jurassic, Comanche, and Cretaceous cycles; it being assumed that erosion throughout that time was essentially with respect to one baselevel and that the residuals which have survived above the Cretaceous baselevel to the present had previously resisted the erosion of all earlier Mesozoic times. Such a view would lead

naturally to an idea in regard to the competency of mountains to endure through Mesozoic time which would be hard to adjust with the conclusions advanced in this article regarding the large degree of the destruction of relief in each of the earlier periods.

The error in assuming one baselevel and a single uncompleted erosion cycle for Jurassic, Comanche, and Cretaceous time can be appreciated best by an examination of the Coastal plain in Maryland and Virginia. At Washington the base of the Potomac can be followed eastward under the Coastal Plain by means of deep wells, that at Meadows penetrating 1511 feet without entering the crystalline rocks below. Irregularities in the margin and the elevation of outliers seem to show a relief to the floor amounting to at least 300 feet, possibly 500 feet, so that the slope as determined by wells is subject to this correction. The larger number of wells and their extension over a zone upwards of twelve miles wide unite in showing, however, that the floor of the Potomac slopes southeastward at Washington about 112 feet per mile. The deposits indicate a fluviatile origin and this surface represents therefore the present inclination of the nearly horizontal baselevel at the opening of Comanche time. The base of the Cretaceous is a marine plain, sloping originally seaward at a grade of perhaps five or ten feet per mile. It is now inclined 33 feet per mile. Clearly one baselevel did not persist through the two periods, since these two planes of deposition are inclined to each other at an angle of 79 feet per mile.

The base of the Potomac is laid upon the floor prepared by Jurassic erosion. The volume of the Potomac gives some indications of the volume of Comanche erosion; and the base of the Cretaceous measures the warping which went forward here during Comanche time. The Potomac group is given in the Patuxent folio as from 540 to possibly 665 feet thick in the region of its outcrop. In the deep well at Fortress Monroe, 65 miles east of the margin of the coastal plain, it is given in the Norfolk folio as 1300 feet in thickness. As the Potomac group consists of freshwater deposits, the sediment must have been more than sufficient to fill the downwarping on the southeast* and implies a Comanche uplift to the northwest so great as to separate completely the Jurassic and Cretaceous baselevels. Most of the residuals above the Cretaceous peneplain probably lie below the Jurassic baselevel of erosion and do not imply therefore their continuous endurance above baselevel since the Permian nor even since the close of Triassic time.

The complete peneplanation of softer formations during Cretaceous time and the large attacks made even on the

* Barrell: Criteria for the Recognition of Ancient Delta Deposits, Bull. Geol. Soc. Am., xxxiii, 405–411, 1912.

resistant areas is the product in very large part of Cretaceous erosion. The fair degree of preservation of that plain upon the resistant rocks and the present broadly mountainous character of the Appalachians are due largely to the comparative recency of the last strong upward movements, which appear to date from the close of the Miocene. The previous moderate uplifts of the early Tertiary had not given the rivers sufficiently steep grades to attack vigorously the regions of resistant rocks, especially those situated near their headwaters.

We look in vain in the Appalachians for the mountains made by the original folding. It was once thought that their time-worn slopes rose still from the present valley floors, even where the folding dated from the close of the Ordovician. Then it was seen that most of the Appalachian mountains were the remnants of a dissected platean which had in the late Mesozoic been a plain of erosion lying near the level of the sea. The mountains existing from the Appalachian revolution were then regarded as those higher masses rising in isolated groups above the plateau. But with further searching the mountains of even Permian folding are found to recede continually like the proverbial foot of the rainbow.

Absence of Structural Relations between Present and Original Limits.

As discussed under the subject of erosion cycles, the tendency in the past has been to draw the original boundaries of formations not far beyond the present limiting outcrops, even where such a conclusion is not suggested by the nature of the strata; the mind is dominated by that which remains in evidence; that which is eroded is no longer visible to testify to its former extent. In the case of folded structures now eroded Willis, as an outgrowth of his work on initial dips and their supposed relation to folds, has crystallized this relationship of outcrop to original limits more definitely and strictly than have other geologists. Under the subject of initial dips, he argues that a line of downwarping during sedimentation determines the axis of a syncline during future compression; an upwarping, the axis of an anticline.* In applying this to the problem of ancient shore lines he states:

"The decided dip from the shore seaward is in a position to be sharply upturned; it may become vertical or overturned. In this position it may become eroded to great depth without much change in the position of its outcrop, which remains marking approximately the ancient shore line." †

* U. S. Geol. Surv., 13th Ann. Report, Pt. II, pp. 253–263, 1893.

† Relations of synclines of deposition to ancient shore lines, Am. Geol., xiii, p. 141, 1894.

In accordance with this view he draws the Upper Devonian shore line through Pennsylvania within from one to five miles of the present limiting outcrops,* following them so closely that a peninsula of land five miles wide is shown extending into his Upper Devonian sea in that region now highly folded and lying between the Susquehanna and Juniata Rivers. Yet the outcrops running so closely parallel and adjacent through Pennsylvania to these postulated shore lines are from 6000 to 9000 feet in thickness.

The truth or error of this principle proposed by Willis for the determination of ancient shore lines,—or better stated, for the determination of the original margins of sedimentary formations, since they need not be necessarily shores,—is of critical importance in paleogeography in general and in the interpretation of the Upper Devonian of this region in particular. It therefore requires detailed discussion.

First must be considered, the validity of the supposed relation of initial dips to the resulting folded structures. On the map (fig. 1, p. 89) it is seen that the anthracite synclinorium corresponds fairly well to the region of greatest thickness of the Upper Devonian. It may be granted that such great lenses of sediment, by producing a downwarp in a deeper competent stratum, predispose the structure to form a synclinorium, and the formations below and above emphasize that tendency. The north-south anticlinorium between Long. 77° and 78° does not show, however, such a predetermination, and in regard to the individual folds it would seem that the competence of the beds and the necessities of mutual adjustment between folds, not to speak of possible deeper forces acting from below, must completely overshadow slight local variations in initial dip. This skepticism regarding such supposed detailed relations is not controverted by any data thus far published.

If an examination of Willis' original article be made, it will be seen that he repeatedly notes a somewhat indeterminate nature of the field data. Furthermore, his discussion starts with the assumption that the shore of Appalachia was near at hand.† In regard to both Massanutten and Bays Mountains all that the data show is a thinning of the strata to the west, not a maximum thickness under the synclines. But postulating a shore a few miles east gives, of course, the necessary initial dip. This reasoning in a circle was not obvious to such a keen thinker as Willis because everyone held that the shore was nearby, and that which is the general dictum tends to be viewed in time as a proven fact. As to the data used in Pennsylvania, it does not seem that here either is demonstrated a real relationship

* Paleozoic Appalachia, Maryland Geol. Surv., vol. iv, Pl. VII, 1900.
† Loc. cit., p. 255.

between variations in original thickness and the locations of individual folds. The data show a general thickening from the northeast end of the anthracite synclinorium toward the Susquehanna River and, more rapidly, from the northwest toward the southeast. There are certain irregularities in the variations, some of them real, some of them due to the imperfections in measurement. On p. 257 and in Pl. XLVIII of the article cited,* for example, the thickness in column 1 would be about 1400 feet greater if the measurements of H. M. Chance had been used instead of those by Sherwood. Further, the diagrams of Pls. LXVIII and LXIX can be interpreted as showing no relationships between initial dips and the individual folds, an interpretation opposite to that which is given.

As another angle of approach to the present topic of relationship between structure and original sedimentary limits, the Appalachians may be compared to the larger plans of the Tertiary mountain chains of Eurasia. From them Suess has shown that in the typical mountain range the folds are overturned and overthrust in a convex arc upon a foreland plain. The complexly folded and uplifted zone is an anticlinorium. If this foreland becomes crumpled and depressed it constitutes a synclinorium,—to use these terms as defined by Van Hise. The synclinorium tends to lie in front of the anticlinorium and to dip beneath it. The overthrust acts through the uplifted mass, not from the ocean. The depressed mass is underthrust, the two tending to slide past each other. The Juras and the Great Valley of Switzerland with its ranges of Molasse hold such a relation to the Alps; the sub-Himalayas to the Himalayas. In both cases these synclinoria contain upper strata made from the debris of the first foldings of the anticlinoria and have been added to the mountain system by a secondary period of folding. The mountains have grown by adding the marginal foreland.

After profound planation across the system the anticlinorium will show older and originally deeper rock formations, the synclinorium those which were younger. To what extent then may we argue that these younger formations never existed upon the anticlinorium and that the steep or overturned limb between them is the original boundary of the sediments? The answer is best given by the study of the Tertiary mountain systems, since evidence of the original distribution of the strata is in many examples not yet wholly destroyed. The Alps and other Eurasian ranges show involved in their higher ranges great thicknesses of Mesozoic rocks. Upon erosion to near the baselevel these would doubtless be in large measure destroyed

* U. S. Geol. Surv., 13th Ann. Report, Pt. II.

and the anticlinorium would show a complex of older and crystalline rocks thrust over the Mesozoic and Tertiary formations on the flanks.

In the Rocky Mountain system examples of sedimentary mantles may be seen in the Bighorn Mountains, the Snowy Mountains north of the Yellowstone Park, and in other ranges. The formations which can be asserted never to have existed on the Rocky Mountain ranges are in general those, like the Laramie and the Tertiary, which have been deposited after the mountains began to grow and show by their nature that they were derived from the mountain waste. Yet if these Cordilleran movements had taken place in the Paleozoic, erosion would since have widely removed the pre-orogenic sedimentary formations from the regions of uplift and an application of this principle used by Willis would result in the drawing of Paleozoic and Mesozoic shore lines where none existed.

We may turn next to the Appalachians and interpret them according to these other examples. The folds of the Great Valley dip southeastward, underthrust beneath the older and metamorphosed terranes which constitute the Appalachian mountains and the Piedmont Plateau. The metamorphic province is structurally an anticlinorium which received its overthrust from the back-land of Appalachia. The Great Valley, with its parallel ranges and fragments of plateaus, is the synclinorium. But the erosion surfaces of Mesozoic and Tertiary origin bevel across both provinces, recognizing only the hardness of the formations and showing only secondary relations to the rock structures. From the analogy of other mountain systems it cannot be held that the formations now restricted to the Great Valley have never existed beyond it. The geosyncline of deposition and the synclinorium of folding are not synonymous, nor coincident in outline. Those parts of the higher formations lying on the anticlinorium would have been destroyed before the present time because of upthrust to elevations higher than the now remaining mountains. The coarse and thick sediments of the later Paleozoic show that extensive movements took place in Appalachia. But these movements may have been east of the present Atlantic coast line and the mantles of waste to which these movements gave rise may have extended far east of the present outcrops. How far is to be determined later.

Let a supposed relation between the synclinorium of the Great Valley and the original limits of the Upper Devonian be tested further by applying the same principle to the still uneroded portions of other Appalachian formations. It will be observed that erosion to sea level, the completion of the present cycle, would remove the Pocono sandstone from the

whole northern half of Pennsylvania. East of the Allegheny plateau it would outcrop only in the steep limbs of the anthracite synclines, to the northeast the whole of the Pocono plateau becoming removed. Following this principle of Willis, our distant descendants would argue therefore from the limits of the outcrops that the Pocono sandstone in eastern Pennsylvania was a local deposit confined to the anthracite coal basins.

As another illustration,—between the New Jersey Coastal plain and the bold Silurian outcrop known as the Kittatinny or Shawangunk mountain is an intensely folded and faulted region 50 to 60 miles in width, now occupied by considerable areas of Cambro-Ordovician limestones and slates. Erosion of the Appalachian province to another mile in depth would destroy most of these rocks and perhaps even the most deeply infolded remnants. Their easternmost outcrops would then appear on the steep walls of the synclinorium of the Appalachian valley. The inhabitants of the earth in such a period would, if they followed the principle which is here under criticism, declare that the Ordovician seas never encroached eastward beyond this margin.

To come to the Upper Devonian formations in particular,—their gradations in thickness across the geosyncline are best revealed in southern Pennsylvania. Proceeding from the west to the east,—at the Allegheny Mountain front they measure 6000 feet; around the isolated Broad Top coal basin between 7000 and 8000 feet, in the southern anthracite basin over 9000 feet. Consequently the suggestion both from the changes in thickness as well as the nature of the sediments is that they formerly extended an unknown distance to the eastward. The original basin has been uplifted on the east and the Upper Devonian formations eroded back to the region of their maximum thickness. How far eastward and southeastward these formations once extended must be estimated from other lines of evidence:—the internal evidence given by the sediments now remaining, and the external evidence as to adequate sources of supply for the original volume of the Upper Devonian waste.

[To be continued.]

SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *The Behavior of the Radio-Elements in Precipitation Reactions.*—Fajans and Beer have discussed this matter in connection with some investigations of their own. The conclusion has been reached by recent researches that the radio-elements fall into groups or pleiads, usually accompanying an ordinary element which may be called the chief element. According to all experience the radio-elements of such a group are not separable by chemical means from the chief element, and their proportions remain unchanged when this element is subjected to fractionation. For instance, there is a group corresponding to lead, another to thorium, another to tellurium, and so on.

The authors consider particularly the precipitations of radio-elements in cases where the chief element is absent. If they are chemically identical with the chief element, they should be precipitated along with any common element by means of any reagent which would also precipitate the chief element in case it were present, and this appears to be their behavior. For instance, radium E, which goes with bismuth, is precipitated almost quantitatively (when bismuth is absent) along with barium carbonate, lead sulphide, copper sulphide, cerium hydroxide, barium sulphate in very weakly acid solution, and by metallic tellurium formed by the action of stannous chloride in weak acid solution, but it is not precipitated with barium sulphate in strongly acid solution, nor with lead sulphate, nor with metallic arsenic precipitated by stannous chloride. Since bismuth, if present in weighable quantity, would behave in the same way, it appears that the radium E, although it was present at the very great dilu- tion of about 10^{-12} moles per liter, followed precisely the bismuth reactions.

The authors discuss the matter much further and conclude that previously assumed adsorption phenomena have little to do with the precipitation of the radio-elements. They believe also that the chemical character of such radio-elements as are not identical with any common element may be shown by their behavior in precipitations.—*Berichte*, xliv, 3486. H. L. W.

2. *A New Source of Gallium.*—This metal, which was discovered by Lecoq de Boisbaudran in 1875 in zinc blende, has been detected spectroscopically in various rocks and mineral waters since the time of its discovery, but there has been no material found which would furnish a convenient supply of this very rare element. It required 4300 kg. of blende to furnish 63 g. of the metal at the time of Boisbaudran's investigations, a yield of only about 0·0015 per cent. Bardel and Boulanger have now detected gallium in samples of commercial aluminium, and the spectroscopic indications of its presence were so strong that they undertook its extraction from

this source. From about 2 kg. of the metal they obtained nearly 4 decigrams of gallium, or a yield of nearly ·02 per cent. Unfortunately the authors describe their method of extraction only very vaguely. They say that the aluminium was treated with hydrochloric acid, that the impurities were separated by means of hydrogen sulphide, either in hydrochloric or acetic acid solution, and that the separation was repeated several times. Probably the gallium was precipitated with the sulphides obtained in acetic acid solution, and thus separated from aluminium, but this point is not made clear.—*Comptes Rendus*, clvii, 718. H. L. W.

3. *Ammonium Peroxides.*—A number of years ago the compound NH_4O_2H (or $NH_3 . H_2O_2$), ammonium hydro-peroxide, was prepared by Melikoff and Pissarjewski. Recently D'Ans and Wedig, by passing dry ammonia into a solution of 98 per cent hydrogen peroxide in absolute ether, at a temperature of about $-10°$ C., have obtained at first beautiful transparent crystals of the compound mentioned above. When more ammonia was passed in, the crystals melted and a heavy oily layer settled out of the solution. The ether then contained much ammonium, but only traces of hydrogen peroxide. The oily layer solidified with difficulty at $-40°$ C., and the crystals thus formed were found to be in the new compound $(NH_4)_2O_2$, or ammonium peroxide. This compound readily loses ammonia with the formation of the other peroxide.—*Berichte*, xlvi, 3075. H. L. W.

4. *The Poison of Toads.*—Wieland and Weil have succeeded in obtaining in a pure condition the poisonous principle excreted from the glands in the skin of toads. They employed the skins of 2000 toads and extracted the crude substance by a long series of operations, obtaining about 20 g. of it. This amorphous product had been obtained previously and named bufotalin. It was known to be free from nitrogen, like the snake poisons. The present investigators were able to purify the product and obtained it in the form of beautiful, transparent, colorless crystals. It was found to have the composition $C_{16}H_{24}O_4$, to be optically active and neutral in its reaction. By a study of its chemical behavior, a considerable, but not complete, knowledge of its structure was obtained.—*Berichte*, xlvi, 3315. H. L. W.

5. *Quantitative Analysis in Practice;* by John Waddell. 8vo, pp. 162. Philadelphia, 1913 (P. Blakiston's Son & Co. Price $1.25 net).—This book presents an introductory course of analysis designed for colleges and universities. Very full and excellent directions are given for the exercises for practice, which, after the complete analysis of barium chloride, magnesium sulphate, and calcium carbonate, consist chiefly of technical analyses of ores and a few other commercial products. Much good advice is given in connection with the operations. There is a section devoted to the inculcation of honesty, which might well be made even more emphatic; accuracy and speed are also discussed, and a very good feature of the book is the statement of the time that should be required for each analysis. It is inevitable that there should

be differences of opinion among teachers of analytical chemistry in regard to some of the details of the operations, as well as the choice of methods, and the selection of the exercises for practice. The book under consideration, therefore, may not be satisfactory in all respects to every teacher, although there is no doubt that it presents a very satisfactory course of work for students in the subject. H. L. W.

6. *The Constitution of Matter;* by JOSEPH S. AMES. Pp. x, 242, Boston, 1913 (Houghton, Mifflin Co.).—In this book is presented the subject-matter of a course of six lectures delivered by the author at the Northwestern University, in February, 1913, on the Norman W. Harris Foundation. Some idea of the ground covered and of the sequence of material discussed may be obtained from the following titles of the respective lectures:—"I. General Properties of Matter; Mass. II. Corpuscles and Atoms; Electrical Mass. III. Radio-activity; Gravitation. IV. Radiation; Formation of Molecules; Elasticity. V. Properties of Metals; Thermionics; Magnetism. VI. Models of Atoms; Conclusions." Since the majority of the audiences consisted of people unfamiliar with both the facts and the methods of science, the manner of presentation is necessarily elementary and non-mathematical. Although the task of preparing such a series of lectures under the given conditions was undoubtedly a very difficult one, nevertheless the text is unqualifiedly accurate and unusually lucid, which is just what would have been expected from the master hand which wrote it. If the general reader would acquire his knowledge of scientific subjects from books of this reliable type instead of from newspapers and magazines, he would obtain correct impressions and perspective and would be more than repaid in efficiency for the extra time and thought expended. H. S. U.

7. *Mechanics of Particles and Rigid Bodies;* by J. PRESCOTT. Pp. viii, 535, with 219 figures. London, 1913 (Longmans, Green and Co.).—The motives which actuated the publication of this volume are clearly stated in the following sentences which are quoted from the author's preface: "The people whose needs were most considered when this book was being written were students aiming for a pass degree at a British university." "The book covers, I think, all that they will require in the subject of applied mechanics except hydrostatics." "The book has a utilitarian bias which should make it useful to the engineering student, and I hope, at the same time, interesting and live to the science student."

The subject-matter is divided into three Parts entitled respectively: "Statics" (239 pages), "Dynamics of a Particle" (161 pages), and "Dynamics of a Rigid Body" (120 pages). The Calculus is used throughout and an appendix on conics immediately follows the last chapter. A special feature of the book consists in the relatively large number (667) of problems for solution by the student, which are collected in groups at the ends of the chapters to which they pertain. Many of these exercises have been taken from "Honours," B.Sc., and other examination papers,

and the answers are given with but few exceptions. The text-figures and type are clear and emphasis is indicated by the judicious use of italics. Also, at the close of the volume, some useful numerical data and an index are given. The book is doubtless admirably adapted to the needs of British students but it gives the impression of being too extensive and detailed for the requirements of most colleges in the United States. H. S. U.

8. *An Elementary Treatise on Calculus;* by WILLIAM S. FRANKLIN, BARRY MACNUTT and ROLLIN L. CHARLES. Pp. x, 294, with 179 figures. South Bethlehem, 1913 (The Authors).—Teachers of physics often find that students who can apply with ease the operations of the calculus to the solution of formal, analytical questions are altogether at sea when it becomes necessary to work out even a simple problem of a practical nature. The authors have not only experienced this difficulty but they have written and printed a book which is especially designed to meet the exigencies of the case. In view of the apparently radical and unorthodox nature of the text the volume has not yet been given to a publishing house but has been printed tentatively in order to find out whether a widespread need for reform is felt by other successful teachers of the subject.

The guiding principle of the presentation is expressed as follows: "We believe that the most important thing in the teaching of calculus is to lead the student to a clear understanding of principles." "Therefore our chief endeavor has been to develop the subject as simply and as directly as possible." This has been accomplished by teaching the student to *think* clearly about the *meanings* of the operations which he performs and not to effectively treat the calculus as a mathematical game which is played with symbols according to certain rules and regulations. For illustration, the subject of integration is introduced by calling attention to the fact that such familiar instruments as cyclometers and watt-hour meters are integrating machines. A discussion of the Amsler planimeter is then followed by an example of "integration by steps" in connection with a speed-time curve of an electric car. After nine pages of this kind of preparation the subject of algebraic integration is begun. The definition of a differential equation is wisely presented as early as page 31. Chapter VII (pp. 168–189) deals with "Some Ordinary Differential Equations" and chapter VIII (pp. 190–209) is entitled "The Partial Differential Equation of Wave Motion." The final chapter (IX, pp. 210–253) is on "Vector Analysis." There are three appendices comprising respectively problems, a table of integrals, and a commentated list of some important books on mathematical theory. To sum up, this text amounts to a homogeneous mixture of the calculus, differential equations, vector analysis, physics, and, above all, common sense. At present there are a great many errors in the numerical answers to the problems but these will doubtless be eliminated before final publication. The only way to get a correct idea of the contents of this admirable book is to procure a copy and read it entirely through, as the reviewer has done. H. S. U.

II. Geology and Natural History.

1. *Conemaugh formation in Ohio;* by D. Dale Condit and Clara Gould Mark. Geol. Surv. Ohio, 4th series, Bull. 17, 363 pages, 16 plates, 1912 [not received at New Haven until July, 1913].—This excellent work, a model in stratigraphy, describes the general and detailed sequence with the local faunas of the Conemaugh formation throughout eastern Ohio. The Conemaugh lies high in the Pennsylvanian system and has a thickness varying between 355 and 500 feet. The irregular deposition of the various sandstones and their channeling through the other deposits, in the main of marine waters, and the peculiar limestone "desiccation conglomerates" are clearly brought out. The fossils of the various limestones have been kept apart and carefully determined and tabulated by Miss Mark. The plates of fossils are the work of Mr. Barkentin. The total number of Conemaugh named species is 162, of which 12 are new. The many diminutive bivalves and gastropods and the abundance of Fusulina are features of these faunules.

The Conemaugh "consists mostly of sandstone, sandy shale and clay, much of which has a reddish brown color. Coal seams and limestones are few and thin. All of the beds are characterized by lack of persistence, and vary greatly as to thickness and appearance from place to place. Local erosion planes and unconformities of small magnitude are extremely abundant and occur at all horizons. These hiatuses are shown by conglomerates and truncated strata. Frequently the material of the conglomerates can be traced to some nearby fossiliferous limestone bed or coal seam.

"Much of the lower half of the Conemaugh formation is of marine origin and has a number of fossiliferous horizons. The highest fossil-bearing beds, lying a little above the middle, mark the final invasion of the sea into the Appalachian basin. All overlying strata lack forms of undoubted marine origin; their fossils being mostly plant remains, certain minute fossils, such as *Spirorbis*, ostracods and gastropods, generally regarded as fresh-water, together with occasional fish, amphibian and reptilian bones. Insect remains are sometimes found well preserved in the shales. The marine limestones of the lower half of the formation are the most persistent and lithologically uniform beds, but even these have suffered contemporaneous erosion and locally failed to form, owing to unfavorable conditions, such as the presence of shoals in the sea and continuous sedimentation from rivers" (15).

"It is undetermined whether the retreat of the sea subsequent to the formation of each fossiliferous limestone was due to elevation of the region, or whether there was a progressive subsidence so pronounced at times as to produce a temporary encroachment of the sea with intermittent pauses of sufficient length to permit

a return of freshwater conditions. The westward thinning of the strata in Ohio suggests derivation of the materials from land areas to the east. . . . The sandstones by their mineral composition have evidently been derived at least in part from a source in crystalline rocks either igneous or metamorphic. . . . . It would seem from the mineral composition of the sandstones that metamorphic rocks were not plentiful in the region from which the sediments were derived. Garnet, a common metamorphic mineral, is entirely lacking in all Carboniferous sandstones of Ohio that have been examined microscopically" (249–251).

"In regard to the correlation of the fossiliferous beds of the Conemaugh with the Pennsylvanian deposits of Kansas the conclusion reached is that the Brush Creek and Cambridge limestones probably correspond to the middle or upper part of the Pottawatomie formation, the Portersville to the upper part of that formation or the lower part of the Douglas, and the Ames to the upper part of the Douglas or lower beds of the Shawnee" (295). C. S.

2. *Caradocian Cystidea from Girvan;* by F. A. Bather. Trans. Roy. Soc. Edinburgh, xlix, Pt. II. Pp. 359–529, 6 pls., 80 text figs., 1913.—This is an elaborate study of nine species (eight new) of uppermost Ordovician cystids of the genera *Dendrocystis* (1), *Cothurnocystis* (2), *Cheirocrinus* (2), and *Pleurocystis* (4), from the Girvan region of Scotland. The work is, however, much more than a study of the forms and genera mentioned, for all of the related material of Europe and America is included and finally adjusted into the phyletic classification.

The final paragraph deserves to be quoted. It reads:

"So does the remote story of these Girvan fossils reveal anew the perpetual warfare of life, its ever unaccomplished task to bring this ancestral burden of the body into perfect harmony with an elusive nature; for, just as that highest hope fails to be fulfilled, the wheel of the world is turned, and the new contest demands competitors of a less wearied stock or a more flexible training. The Palaeontologist may be one who deals with creatures that are what we call 'dead and buried,' but he above all men should be filled with a sense of the living drama that underlies his science: the unending struggle of the past as crystallized in organic form with the ever new surroundings of a shifting universe; the clash of inherited structure, habit, thought, against the iron necessities of the present. The figured stone, rudely cast aside by the quarryman or blindly treasured by the curio-hunter, is for him an emblem of shattered conventions and creeds outworn; it is his material proof of the eternal Nemesis."

C. S.

3. *A Contribution to the Paleontology of Trinidad;* by Carlotta Joaquina Maury, with drawings by Gilbert Dennison Harris. Jour. Acad. Nat. Sci. Phila., 2d ser., xv, pp. 25–112, pls. v–xiii, 1912.—The work of Guppy has long since attracted the student of Tertiary faunas to Trinidad. As asphalt occurs in

quantity here, Doctor Veatch is working out the geology of these deposits for the General Asphalt Company of Philadelphia, and Miss Maury the paleontology. In the present work are described 128 species, a very few from the lower part of the Cretaceous, the bulk from the Eocene and Oligocene. The new subgenus of gastropods, *Veatchia*, is proposed.

The author points out for the first time that basal Eocene occurs on Soldado Rock, Trinidad. Further, that "the Alabama Midway Eocene and the Pernambuco beds of Brazil" are linked by common species. This is a valuable correlation, for the Pernambuco fauna has long puzzled stratigraphers. More often it has been regarded as of Cretaceous age, but the commingling of Trinidad and Pernambuco species proves that the last named fauna is also of Midway Eocene time. The author also states that "the age of the shelly asphalt on the Brighton beach is Oligocene—and late Oligocene, perhaps about equivalent to the Chipolan of Florida" (27). C. S.

4. *Formation of Coal Beds;* by JOHN J. STEVENSON, 1911–1913.—During the past three years Professor Stevenson has been publishing in the Proceedings of the American Philosophical Society a series of four articles under the above title (see review in this Journal, XXXV, 546, May, 1913). These papers are now brought together in book form, with their own pagination, title page, preface, and table of contents. In addition, the whole is made more accessible through a very good index in two parts, one of authors cited and the other of a general nature.

This great work, a labor of love, is indispensable to all students of the Coal Measures, whether practical, stratigraphic, historical, or biologic. It is a remarkable record of industry in a geologist of more than three score years and ten. C. S.

5. *Contributions to the Geology of the Nordingrå Region;* by J. M. SOBRAL. 8vo, pp. 177, pls. xii, map in cover. Upsala, 1913.—This is a very careful, detailed study of a small area of crystalline rocks on the east coast of Sweden. Inland the area is bounded by the Archean and the rocks described occur as intrusions along the coast; there are small amounts of sedimentary rocks in contact with them, quartzites and arkoses. The igneous rocks are granites, monzonites, gabbros and anorthosites. The field occurrences and relations of these rocks are minutely described and considered, their petrography treated in detail, and many analyses of the types given; it is indeed chiefly a petrographic study.

To one of the feldspathic dikes of the district the name of *Värnsingite* is given; the rock consists mostly of albite, with some pyroxene, titanite, magnetite and apatite; with epidote, prehnite, and muscovite as alteration products. The analysis shows approximately 56 per cent of silica, 16 of alumina, 7 of lime, 5 of magnesia, 6 of soda, with only a minute quantity of potash and about 4 per cent of iron oxides. The grain is rather coarse. The author brings it into relation with albitites of other regions. L. V. P.

6. *West Virginia Geological Survey, County Reports, 1913. Cabell, Wayne and Lincoln Counties;* by C. E. Krebs, Assistant Geologist, and D. D. Teets, Jr., Field Assistant. Pp. 483, pls. i-xxvi, 6 figs., 7 maps in separate cover.—In common with the county reports previously published by the West Virginia Survey, the present volume deals chiefly with economic resources,—coal, petroleum, natural gas, structural material, and soils. Numerous detailed sections of the Dunkard, Monongahela, Conemaugh, Allegheny and Pottsville series are given. H. E. G.

7. *West Virginia Geological Survey: Marion, Monongalia, and Taylor Counties;* by Ray V. Hennen, Assistant Geologist, assisted by David B. Reger, Assistant Geologist, 1913. Pp. xvii, 844, pls. I–XXXIII, 11 figures including 2 maps. Report accompanied by 3 maps in separate case showing (I) Topography, (II) General and Economic Geology, (III) Agricultural Soils, of the region reported upon.—The report on Marion, Monongalia, and Taylor Counties covers one of the richest areas in the Appalachian region, so far as coal, oil, and gas are concerned. The Pittsburg coal seam here reaches its greatest development. In addition to very detailed areal and economic descriptions the authors devote considerable space to a discussion of the stratigraphy of the Carboniferous. H. E. G.

8. *Iowa Geological Survey, Volume XXII, Annotated Bibliography of Iowa Geology and Mining;* by Charles R. Keyes. Pp. 908, 1913.—In addition to an exhaustive descriptive bibliography of Iowa geology and geography, Dr. Keyes has prepared the following interesting chapters: On geographical exploration of Iowa land (pp. 15–44); geologic reconnaissance in Iowa (pp. 45–88); an historical sketch of mining in Iowa (pp. 89–121), and systematic geologic surveying in Iowa (pp. 123–144). H. E. G.

9. *Permo-Carboniferous Vertebrates from New Mexico;* by E. C. Case, S. W. Williston, and M. G. Mehl. Pp. i, 81; one plate, 51 figs. (Carnegie Institution of Washington, Publication No. 181) Washington, 1913.—This highly important contribution to our knowledge of Paleozoic Vertebrata will be read with great interest, as it emanates from the pens of the foremost American authorities upon these hitherto obscurely known forms. The work embodies the results of the latest exploration in the Southwest which has done much to clarify the obscure stratigraphy of the fossil-bearing beds, and which has added the knowledge based upon whole skeletons where but fragmentary remains were known before. Chapter I, by Case and Williston, describes the bone-bearing beds of north-central New Mexico. The results are summarized as follows:

"The Upper Trias rocks, about 600 feet in thickness, perhaps more, are predominantly softer and lighter colored, often orange-colored, yellowish, and whitish, and more aeolian in character, with the upper or uppermost beds more or less gypsiferous. These beds, as in the Lander region, have basal sandstones, reddish or white, with conglomerate and clay layers below them

yielding phytosaur and labyrinthodont bones (both types were found at El Rito), corresponding well with like vertebrates from the Keuper of Europe. Below these beds there are not less than 350 feet (in the Lander and Kansas regions perhaps 900 feet) of more uniform red sandstones and clay layers, usually weathering into more vertical bluffs, that are utterly barren of all fossils and supposed to be of Lower Triassic and Upper Permian age. Below these, and conformable with them, in New Mexico and probably elsewhere are not less than 300 feet, probably more, of prevailing coarser and darker colored, often brownish sandstones, and dark-colored clay beds, yielding vertebrate remains hitherto considered to be of Permian age, but which in all probability are, in part at least, of upper Pennsylvanian age" (pp. 5, 6).

Then follows a list of known vertebrates from the Permo-Carboniferous beds of New Mexico, including a shark, five genera of amphibians and ten of reptiles.

Chapter II, also by Case and Williston, amplifies the description of the amphibian *Aspidosaurus novomexicanus*, of which the type specimen is preserved at Yale. Chapter III, by Mehl, describes a new genus and species of Stegocephalian, *Chenoprosopus milleri*, of which the peculiar elongated skull alone is surely known, there being some doubt as to the identity of an associated vertebra.

Chapter IV is again by the two senior authors, and describes the nearly complete skeleton of the reptilian species, *Diasparactus zenos*, supposed with others of its family to have been a marsh-dweller, a very sluggish, harmless eater of vegetation or small invertebrates, able to present no more than a passive defense against the attacks of the larger carnivorous forms.

Chapter V, by the same two writers, has for its subject a nearly complete skeleton of the reptile, *Ophiacodon* Marsh, of which the type material is also at Yale. The new specimen lay almost completely articulated in the rock and has been entirely restored and mounted at the University of Chicago. *Ophiacodon* was neither a swimming nor a burrowing animal, but was slow moving, and doubtless spent its life about the flat marshes and low plains, feeding upon such small reptiles and amphibians as it could secure. Its long, slender, recurved teeth were well adapted for the capture of slippery creatures, but, with the jaws, they were too weak to withstand much struggling of strong-bodied prey.

The chapter also includes a description of *Scoliomus puercensis*, new genus and species, a pelycosaur.

In Chapter VI, Case and Williston give a description of bones referred to *Sphenacodon* Marsh. This is a carnivorous reptile of rapacious habits, to judge by its teeth, and aside from this is chiefly interesting in showing to a certain extent the peculiar elongation of the vertebral spines so characteristic of its more noted relatives, *Dimetrodon* and the bizarre "ship-lizard," *Naosaurus*. In *Sphenacodon* the spines are extraordinarily long for a reptile,

but could not have formed any such frill as that of *Dimetronod* or the basilisk lizard.

The authors go on to say:

"And this structure of the vertebra has an important bearing in any discussion as to the meaning of the spines in *Dimetrodon*. That *Dimetrodon* could have developed such extraordinary spines without affecting to a great degree the characters of the skeleton proves conclusively their relative physiological unimportance.* Certainly, had the enormous dorsal expansion of *Dimetrodon* been of profound importance in the life economy of these creatures, it must have materially affected the structure of the skeleton elsewhere. That *Sphenacodon* is more primitive than *Dimetrodon* must be admitted to be perhaps another bit of evidence of the greater antiquity of the New Mexico deposits than the upper ones, at least, of Texas" (p. 69).

The last chapter, by Williston and Case, describes *Edaphosaurus* Cope, with a new species, *E. novomexicanus*. The type skull, although somewhat fragmentary, "is of importance as furnishing for the first time indubitable evidence of the relationship of *Edaphosaurus* and *Naosaurus*," whereas the "relationships of *Edaphosaurus* and *Dimetrodon*, notwithstanding the similarity of their dorsal spines, cannot be very intimate. The conclusion is irresistible that these resemblances were, for the most part at least, merely the result of convergent evolution." R. S. L.

10. *The Meaning of Evolution;* by Samuel C. Schmucker. Pp. 1–298; with frontispiece and 7 illustrations. New York, 1913 (The Macmillan Company).—This book fulfils the author's purpose, that of presenting a simple, readable statement so that the "average person" having no special training in the sciences may be brought to an understanding of the doctrine of evolution.

Chapter I is an historical summary of the development of the evolutionary idea from the time of the earliest writer, Anaximander, 600 B. C., until the coming of Darwin. The following chapter sets forth the never-to-be-forgotten career of Darwin, the co-discovery of the idea of natural selection by Darwin and Wallace and the rare example of scientific chivalry these men gave the world. Chapter III treats of the underlying idea of evolution, laying special emphasis upon the four basic conceptions of heredity, variation, multiplication, and selection. The next two chapters deal with adaptation,—one with that of the individual in clothing, color, protective attitudes, weapons, and so on, and the other that of the species, especially in the features wherein the contrast of the sexes lies. The author, while realizing the doubt

* "Case would hesitate to endorse the statement that these elongated spines were physiologically unimportant. He has long considered (and frequently stated his belief) that the enormous development of the spines in *Dimetrodon* and probably also in *Edaphosaurus* (*Naosaurus*), imposed upon the creatures a physiological burden so great in its demands upon the energies of the individual, both for their original production and the repair of frequent injuries, that it was an important, if not the chief, cause of their extinction."

cast upon the Darwinian factor of sexual selection, would retain the idea tentatively even though an interrogation point be placed behind it, as the rejection of this factor leads to as many difficulties as its retention.

Chapter VI discusses the past history of the globe, La Place's nebular theory of earth origin being compared with the later planetesimal theory of Chamberlin and Moulton. A brief geologic table is given with a summary of Historical Geology. In the seventh chapter we are told of the development of the mammals, which leads up to the classic story of the horse, based largely upon data furnished by the American Museum of Natural History. In Chapter IX the evolutionary theories since Darwin are given place, with some of the modern objections to Darwinism.

The last two chapters, "The future evolution of man" and "Science and The Book," are more in the line of moral evolution than the remainder of the volume. The book, while necessarily not profound, and not wholly without certain inaccuracies, is very readable and will serve very well indeed to stimulate further interest. R. S. L.

11. *The First Principles of Evolution;* by S. Herbert. Pp. ix, 346; 90 illustrations and tables. London, 1913 (Adam and Charles Black).—This book, like the previous one by the same author, "The First Principles of Heredity," is the outcome of a series of lectures given to a class of workingmen and others.

The introduction speaks of evolution in general—the usual more or less hazy conception of the term, and what it really implies. Section I, Inorganic Evolution, is treated under the several captions: cosmic evolution, geological evolution, atomic evolution, and evolution of life from the non-living. Section II, Organic Evolution, is divided into two parts, the first of which deals with the facts of evolution, the evidence being taken from morphology, embryology, classification, paleontology, and geographical distribution; while Part II discusses the theories of evolution, beginning with an historical summary, and taking up Lamarckism, Darwinism, and the difficulties of the theories, especially of Neo-Lamarckism and Neo-Darwinism. Under the theories of evolution are also discussed heterogenesis and orthogenesis.

In summing up the theories of evolution, the author says: "Natural selection is at present, so far as it goes, the only acceptable theory of adaptation; for Lamarckism cannot be considered as proven, so long as its basis, the inheritance of acquired characters, has not been established; and teleological vitalism, whilst assuming a purposeful end, is far from having proved its thesis. But—and here it is that the deficiency of natural selection makes itself apparent—while natural selection explains the further development of adaptive variations, once they have attained survival-value, it certainly cannot account for the 'origin of the fit'" (p. 223). It is to solve this problem that the mutation theory and that of orthogenesis have been proposed.

The third section treats of superorganic evolution, including such topics as mental evolution, moral evolution, and the evolution, mainly cultural, of man, followed by a discussion of the evolution of society and the conclusion, the formula of evolution and the philosophy of change. A list of works which is intended merely as a first guide to the literature of each subject dealt with in the work is appended. It is an interesting commentary upon the lack of appreciation of the work of the modern paleontologist that the four works to which one is referred under the heading of paleontology are Darwin's Origin of Species, Wallace's Darwinism, Spencer's Principles of Biology, and Romanes's Darwin and After Darwin, none of which should be for an instant undervalued, but which nevertheless can hardly be said to sum up the *documentary evidence* for the truth of the evolutionary doctrine which is accumulating so rapidly. The glossary and index make still more available and intelligible this excellent work. R. S. L.

12. *Geology and Ore Deposits of the San Francisco and Adjacent Districts, Utah ;* by B. S. Butler. Pp. 212 ; 51 pls., 16 figs. U. S. G. S. Prof. Paper 80, 1913.—The rocks of this district consist of sedimentary formations, lava flows, and intrusions. The sedimentary rocks were deposited from Cambrian to Triassic times, later being elevated and eroded. During Tertiary time there occurred an extensive outpouring of lavas which are mostly quartz latites. At a later period there was also an extrusion of basalt rocks. The extrusion of the main bodies of lavas was followed by extensive intrusions of quartz monzonites in the form of stocks. The present structure of the region has been reduced largely by faulting.

The deposition of the ores of the district followed closely the intrusion of the quartz monzonite. They are all of similar origin but differ in character according to the rock in which they were deposited. There are three general types, namely: deposits of copper ores in quartz monzonite of the replacement vein type, contact copper deposits in limestone and replacement fissure deposits containing chiefly lead and silver in limestone; replacement fissure lead and silver deposits in the igneous rocks. Many of the deposits have undergone secondary enrichment.

In addition to the common minerals of such deposits the following rarer species have been observed in the district: molybdenite, covellite, wurtzite in small hexagonal pyramidal crystals, thaumasite, corkite, brochantite, linarite, beaverite (a new species described in this Journal, xxxii, 418, 1911), jarosite, and plumbojarosite. W. E. F.

13. *The Nickel Industry, with Special Reference to the Sudbury Region, Ontario ;* by A. P. Coleman. Pp. 186; 63 pls., 14 figs., 9 maps. Department of Mines, Canada, 1913.—This monograph describes the geology of the Sudbury region and its nickel ore deposits. It includes a history of the district and detailed descriptions of the various mines. It includes also brief descriptions of the other important nickel deposits of the world. It closes

with a discussion of the metallurgical methods used in smelting the various ores. W. E. F.

14. *The Curious Lore of Precious Stones;* by GEORGE FREDERICK KUNZ. Pp. 406, with numerous plates and figures. Philadelphia, 1913 (J. P. Lippincott Company).—The scope of this book is well expressed in the sub-title, which reads as follows: "being a description of their sentiments and folk-lore, superstitions, symbolism, mysticism, use in medicine, protection, prevention, religion, and divination. Crystal gazing, birthstones, lucky stones and talismans, astral, zodiacal and planetary." To any one interested in gem stones this book will be a treasure house of curious information. Precious stones have always been objects of admiration and desire, and it was inevitable that a host of superstitious fancies should gather about them. The history of the different stones is told at length with many references to early writers, and is accompanied with a large number of interesting illustrations. While giving all the details in a scientific manner, the subject-matter has been so well arranged and presented as to be eminently readable. It is doubtful if there is anyone else living so well fitted by experience and knowledge to write such a book as Dr. Kunz.

W. E. F.

15. *Botanical Features of the Algerian Sahara;* by WILLIAM AUSTIN CANNON. Publication No. 178 of the Carnegie Institution of Washington. Pp. vi, 81; 36 plates; 1913.—In this interesting work Dr. Cannon gives the results of field studies carried on during the years 1910 and 1911. The deserts of Algeria are first discussed with respect to their geographical and climatic characteristics. The vegetation from various parts of the area studied is then described in detail, the most abundant and conspicuous species being listed. In the closing chapter the vegetation is treated from a more general standpoint and compared with the vegetation of southern Arizona. The plates, reproduced from photographs, are unusually clear; they show not only the general aspects of the vegetation but also the habits of certain individual species. A. W. E.

16. *Wissenschaftliche Ergebnisse der Deutschen Zentral-Afrika-Expedition 1907–1908, unter Führung Adolf Friedrichs, Herzogs zu Mecklenburg.* Band II, *Botanik*, edited by Dr. J. MILDBRAED, Berlin. Lieferung 6, pp. 509–601, pl. 68–78. Leipzig, 1913 (Klinkhardt & Biermann).—The first five parts of this volume have already been noted in this Journal (vol. xxxv, p. 335, 1913). The present part includes the second instalment of the Dicotyledoneæ-Sympetalæ and the third of the Dicotyledoneæ-Choripetalæ. Various botanists, mostly from Berlin, have taken part in its preparation. A. W. E.

17. *Laboratory Manual and Notebook in Botany;* by WILLARD N. CLUTE; pp. viii, 70. Boston (Ginn & Company).—This little work gives directions for carrying on the laboratory exercises in a half year's course in elementary botany. It consists almost entirely of questions which the student is supposed to answer from material supplied by the teacher. A. W. E.

18. *An Introduction to the Chemistry of Plant Products ;* by Paul Haas and T. G. Hill. Pp. xii, 401. London and New York, 1913 (Longmans, Green and Co.).—In view of the unmistakable success with which those aspects of biochemistry dealing more particularly with animal physiology have been investigated and presented in text-book résumé in recent years, it is surprising that so few efforts have been made along similar lines in the domain of the chemistry of vegetable forms. The present work aims to furnish an introductory account of the chemistry and biological significance of some of the most important substances occurring in plants. Wherein the distribution of emphasis differs from what one finds in a manual of animal physiological chemistry is indicated by the major subdivisions of the text into : 1. fats, waxes, oils, and phosphatides ; 2. carbohydrates ; 3. glucosides; 4. tannins; 5. pigments; 6. nitrogen bases; 7. colloids; 8. proteins ; 9. enzymes. A few of the important quantitative methods like those applied to the characterization of fats and the estimation of sugars and proteins are described in detail.

The authors have exhibited ingenuity in applying the newer knowledge in this field to the specific needs of students of botany. The result represents an innovation in the way of indicating the progress which the special chemistry of plants has lately made.

L. B. M.

19. *Modern Problems of Biology ;* by Charles Sedgwick Minot. Pp. ix, 124, with 53 illustrations. Philadelphia, 1913 (P. Blakiston's Son & Co.).—The six lectures, delivered by the American exchange professor at the University of Jena in 1912, and originally published in German, are here rendered in English. These lectures touch upon the most fundamental problems of modern biology, the topics discussed being : the new cell doctrine; cytomorphosis; the doctrine of immortality, the development of death; the determination of sex; and the notion of life. Having been designed for a popular audience, the presentation is made in as simple language as the subject will permit. This little book furnishes a reliable summary of the present state of our knowledge on these important topics. There is appended an explanatory list of the principal publications to which reference is made.

W. R. C.

20. *A Laboratory Manual of Invertebrate Zoölogy;* by Gilman A. Drew. Second edition, revised. Pp. ix, 213. Philadelphia and London, 1913 (W. B. Saunders Co.).—The original edition of this book has been widely adopted. The revised edition incorporates a number of changes resulting from more recent laboratory experience, with directions for the study of a few additional forms. The inclusion of a brief literature list for each topic will prove of value both to teacher and student.

W. R. C.

21. *Heredity and Memory ;* by James Ward. Pp. 56. Cambridge, 1913 (University Press).—This lecture, delivered at Newnham College in 1912, explains and supports the psychologic or mnemic theory of heredity, which has received considerable

attention in Europe in recent years. The essentials of this theory are that every living cell has an "organic memory," and that the development of the embryo is "actually and literally a habit," with "the more repetitions the more fixity." "In short, what habit is for individual life that is heredity for racial life." That there should be a physical basis for the hereditary mechanism is not considered important! W. R. C.

22. *A Bibliography of the Tunicata, 1469–1910;* by JOHN HOPKINSON. Pp. xii, 288. London, 1913 (The Ray Society).—This is a companion to the three volumes of the beautifully illustrated monograph of the British Tunicata published by the Ray Society since 1904 (see notices in this Journal). It contains a remarkably complete list of the publications which relate to this group of animals. Not only are all the technical and special papers included, but also the references in textbooks and in other articles dealing with each of the several branches of biology.

W. R. C.

23. *The British Parasitic Copepoda: Copepoda Parasitic on Fishes;* by THOMAS SCOTT and ANDREW SCOTT. In two volumes: Vol. I, text, pp. xi, 252, with 2 plates; Vol. II, plates I to LXXII. London, 1913 (The Ray Society).—In Dr. Brady's monograph on the free and semi-parasitic Copepoda, published by the Ray Society more than thirty years ago, the forms parasitic on fishes were excluded as requiring treatment in a separate volume. The work on these forms has now been completed. The treatise consists of a general account of the structure and habits of this important group of parasites, with full descriptions of the 113 species known from the region covered by the monograph. All of these species are illustrated with anatomical details, and most of them are shown in natural colors in the 72 plates of the second volume.

W. R. C.

24. *The Weathering of Aboriginal Stone Artifacts, No. 1: A Consideration of the Paleoliths of Kansas;* by N. H. WINCHELL. Pp. xiv, 186; 20 text figs., 19 plates. Collections of the Minn. Hist. Soc., vol. xvi, part I. St. Paul, Minn., 1913.—The author believes he has found a sequence of six cultures just south of the Kansas moraine in Kansas. His classification comprises early paleolithic, paleolithic, early neolithic (2 stages), and neolithic (2 stages). The term paleolithic is applied to the culture that antedated the Kansan Glacial epoch. Early neolithic covers the period between the Kansan and Wisconsin Glacial epochs, and neolithic applies to post-Wisconsin culture. This classification is based on the form and patination of the artifacts.

GEORGE GRANT MACCURDY.

OBITUARY.

Dr. ANTON FRITSCH of Prague, director of natural history in the Royal Bohemian Museum and professor of zoology in the University, died on November 15 at the age of eighty-one years.

Dr. HENRY POTONIÉ, well known for his work in botany and paleobotany, died on October 28 in the fifty-sixth year of his age.

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CONTENTS.

Page

ART. I.—Determination of Mineral and Rock Densities at High Temperatures; by A. L. DAY, R. B. SOSMAN, and J. C. HOSTETTER 1

II.—Notes on a new occurrence of Pisanite and Arsenopyrite, and some large Staurolite Crystals from the Ducktown District, Tennessee; by F. R. VAN HORN 40

III.—Diagrammatic Representation of Volcanic Phenomena; by F. A. PERRET. (With Plates I to IV) 48

IV.—Nipa-palm in the North American Eocene; by E. W. BERRY 57

V.—Modification of the Usual Method of Correcting Silica for Included Salts; by S. B. KUZIRIAN 61

VI.—Electrometry with the Displacement Interferometer; by C. BARUS 65

VII.—Upper Devonian Delta of the Appalachian Geosyncline; by J. BARRELL 87

SCIENTIFIC INTELLIGENCE.

Chemistry and Physics—Behavior of the Radio-Elements in Precipitation Reactions, FAJANS and BEER: New Source of Gallium, BARDEL and BOULANGER, 110.—Ammonium Peroxides, D'ANS and WEDIG: Poison of Toads, WIELAND and WEIL: Quantitative Analysis in Practice, 111.—Constitution of Matter: Mechanics of Particles and Rigid Bodies, 112.—Elementary Treatise on Calculus, 113.

Geology and Natural History—Conemaugh formation in Ohio, 114.—Caradocian Cystidea from Girvan: A Contribution to the Paleontology of Trinidad, 115.—Formation of Coal Beds: Contributions to the Geology of the Nordingrå Region, 116.—West Virginia Geological Survey, County Reports, 1913.—Iowa Geological Survey: Permo-Carboniferous Vertebrates from New Mexico, 117.—The Meaning of Evolution, 119.—First Principles of Evolution, 120.—Geology and Ore Deposits of the San Francisco and Adjacent Districts, Utah: Nickel Industry, with Special Reference to the Sudbury Region, Ontario, 121.—Curious Lore of Precious Stones: Botanical Features of the Algerian Sahara: Wissenschaftliche Ergebnisse der Deutschen Zentral-Afrika-Expedition 1907-1908: Laboratory Manual and Notebook in Botany, 122.—Introduction to the Chemistry of Plant Products: Modern Problems of Biology: A Laboratory Manual of Invertebrate Zoölogy: Heredity and Memory, 123.—Bibliography of the Tunicata, 1469-1910: British Parasitic Copepoda; Copepoda Parasitic on Fishes: Weathering of Aboriginal Stone Artifacts, No. 1, 124.

Obituary—A. FRITSCH: H. POTONIÉ, 124.

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VOL. XXXVII. FEBRUARY, 1914.

Established by BENJAMIN SILLIMAN in 1818.

THE AMERICAN JOURNAL OF SCIENCE.

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FOURTH SERIES

VOL. XXXVII—[WHOLE NUMBER, CLXXXVII].

No. 218—FEBRUARY, 1914.

WITH PLATES V–VII.

NEW HAVEN, CONNECTICUT.

1914.

THE TUTTLE, MOREHOUSE & TAYLOR CO., PRINTERS, 123 TEMPLE STREET.

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AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

ART. VIII.—*Geologic Reconnaissance of the Ayusbamba (Peru) Fossil Beds;* by HERBERT E. GREGORY.*

Introduction.

ON the basis of information furnished by Dr. A. A. Giesecke, President of the University of Cuzco, a preliminary excursion to the hacienda of Ayusbamba, province of Paruro, was made by Dr. George F. Eaton in October, 1912. The object of this visit was to investigate the reported discovery of fossil vertebrate remains. The region appeared to Dr. Eaton of sufficient interest to warrant further field work, and accordingly, under instructions from the Director of the Peruvian expedition, arrangements were made for a week's study of the Ayusbamba area. The party which left Cuzco on November 13, 1912, equipped for geologic and topographic work, and for making collections of fossils, consisted of Herbert E. Gregory, geologist; George F. Eaton, osteologist; K. C. Heald and Carlos Duque, topographers; and Jose Gabriel Cosio, professor of Sociology and History in the University of Cuzco.

Geography.

From Cuzco the trail to Ayusbamba enters the valley of the Huancaro, and follows the south branch of that stream to its source in the bogs of the upper plateau, at an elevation of 13,500 feet. Passing over the gracefully molded, grass-floored highland which marks the upper extent of the tributaries of the Rio Huatanay, the trail enters the Apurimac watershed. Perched high on mountain flanks, heading canyons, traversing fields of *yareta*, and zigzagging among glacial bowlders, along spurs and down talus slopes, the path winds its way toward

* Geologist, Peruvian Expedition of 1912.

the Apurimac River and finally emerges at the hacienda of Ayusbamba, ten leagues south of Cuzco (fig. 1). For generations this trail has been the main avenue of approach to the sacred city from the upper Apurimac valley, and the artificial pavements, terraced descents, and trenched hillsides give evidence of an originally well-planned highway, whose construction involved a prodigious amount of physical labor, the value of which is greatly reduced by the present neglect of maintenance. In traversing this route from Cuzco to Ayusbamba, one is impressed by the thought that the llamas and picturesque Indians met on the trail, the grass-covered slopes, the cacti and tenaceous shrubs along the path and bordering the artificial

Fig. 1.

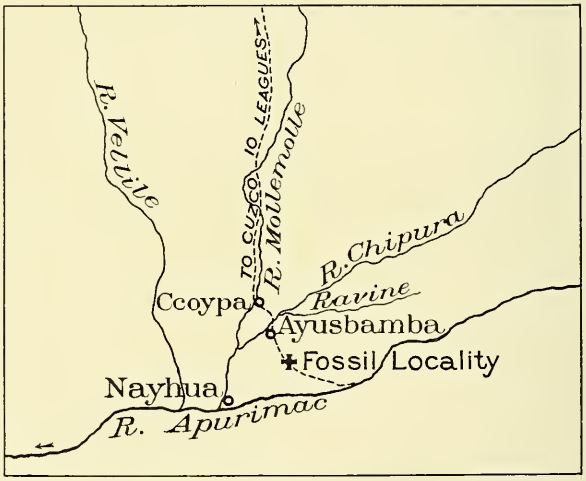


Fig. 1. Index map, showing location of Ayusbamba.

walls, the wonderfully beautiful native flowers which carpet the bowl-like upper valleys, and the long vistas of canyon and slope present a picture essentially identical with that viewed by Inca and pre-Inca travelers. For eight or ten centuries this well-worn path has marked the passage of llama trains and patient Quichua cargadores bearing materials of trade to and from Cuzco.

Along the route are several squalid villages—groups of thatched adobe or stone huts—the homes of the Andean shepherds. Midway between Cuzco and Ayusbamba the trail makes a descent of 2000 feet and passes through Yaurisque at a point where a canyoned stream is joined by two short, wide valleys. The limestone soil, abundant water and sheltered

position of this valley afford opportunity for the cultivation of potatoes, garden vegetables and grains, while the adjoining slopes and highlands furnish admirable pasturage. When viewed from the trail perched high above the village, the deeply trenched canyon along which a swift stream winds its way through a tangle of shrubs, the abrupt slopes of brown

FIG. 2.

FIG. 2. View of the village of Yauriska, looking north.

sandstone dotted with hardy plants, and the graceful outlines of the mountains beyond, compose an attractive landscape (fig. 2). The masses of color presented by field and ledge and native vegetation are pleasantly modified by scattering Eucalypti and a profusion of flowers along the walls and in the better-kept gardens. The village itself—about one hundred, tile-roofed, mud-walled houses, arranged along a cobble-paved

street and adjoined by yards surrounded with forbidding, cactus-covered walls—is in harmony with its topographic setting. However, too close inspection of the village and its inhabitants may detract from the picture, for, in spite of hospitality of priest and official and the evident desire to honor the stranger, it is difficult to overlook the dirt and squalor, the intimate association of man and beast, and the palpably unwholesome manner of life in this typical Andean settlement.

The village of Ccoypa, while not so beautiful as Yaurisque, is equally interesting, especially as regards its location. Situated at the base of a talus slope, the houses of Ccoypa are built among bowlders whose size almost equals that of the individual dwellings, and the streets and the passages constitute a labyrinth which puzzles the stranger.

The hacienda of Ayusbamba, the objective point of our geological excursion, is a typical residence of the wealthier landed proprietor on the Andean plateau. A one-story building of stone, adobe and tile surrounds a spacious patio. The sun-warmed rooms on the north side, including a *sala* of generous proportions, are occupied by the family. The other parts of the building are devoted to store rooms and stables. Intimately connected with the main building are corrals for stock, and a scattering group of huts which house the workmen and their families. At the north, and entered from the *sala*, is the garden, bordered by towering Eucalypti and including flowers and shrubs remarkable for abundance, variety, and individual merit. To me the most attractive feature of this hospitable home is the view from the garden terrace northward across the Chipura chasm to the terraced fields of Ccoypa, and northwestward across the Mollemolle into the magnificent canyon of the Apurimac (figs. 3 and 4). These views, though uncommon among the world's scenic features, are characteristic of the Peruvian Andes. The hacienda has its own supply of food, fuel and material for clothing, and has workmen skilled in various trades. Little needs to be bought and little is sold; the place is commercially almost self-sufficient. The Indians, young and old, are not merely hired servants, but are attached to the hacienda by various ties. The relation of señor to servants and workmen, and the general régime at Ayusbamba, remind one forcibly of a mediæval feudal estate in which independence and hospitality were closely mingled.

General Geologic Relations.

The area including Ayusbamba possesses great relief. The lower reaches of the smaller streams (Vellile, Mollemolle, and Chipura) are bordered by steep, frequently precipitous slopes, and the master stream, the Apurimac, whose volume goes to

swell the Amazon, has entrenched itself 4000 feet below the general level. In passing from Cuzco to Ayusbamba the dividing flats and low ridges form a roughly level surface extending over sedimentary beds in various attitudes, and of unequal

FIG. 3.

FIG. 3. View from Señor Calvo's garden looking north across the Chipura gorge. The trail to Cuzco traverses the rock terrace, passes through the village of Ccoypa and ascends the valley of the Mollemolle.

resistance to erosion. Although deeply dissected, the highland area suggests a widespread though imperfectly developed peneplain resulting from erosion in late Mesozoic time. Where unaffected by glaciation, the valleys cut into this ancient, base-leveled floor have reached a stage of development approaching

maturity. A glance into the Apurimac canyon (fig. 5) shows that the present valley form has by no means been attained by regular progressive growth within a single cycle. At least two rock benches and two alluvial terraces occupied by small

Fig. 4.

Fig. 4. View from Señor Calvo's garden, looking northwestward, down the Mollemolle into the Apurimac canyon.

Andean villages mark the valley wall,—facts which indicate an involved physiographic history whose episodes await interpretation.

The higher mountain valleys are flat-floored, wide open, bounded by steeply-sloping walls which join the plateau surface at an abrupt angle. To these evidences of glaciation may

be added morainal accumulations and the ungraded character of the upper stream courses, which are in marked contrast with their lower reaches. So far as observed, direct abrasion by glaciers was not effective below 12,500 or at most 12,300 feet. The mountain heights above the lower limit of ice action pre-

FIG. 5.

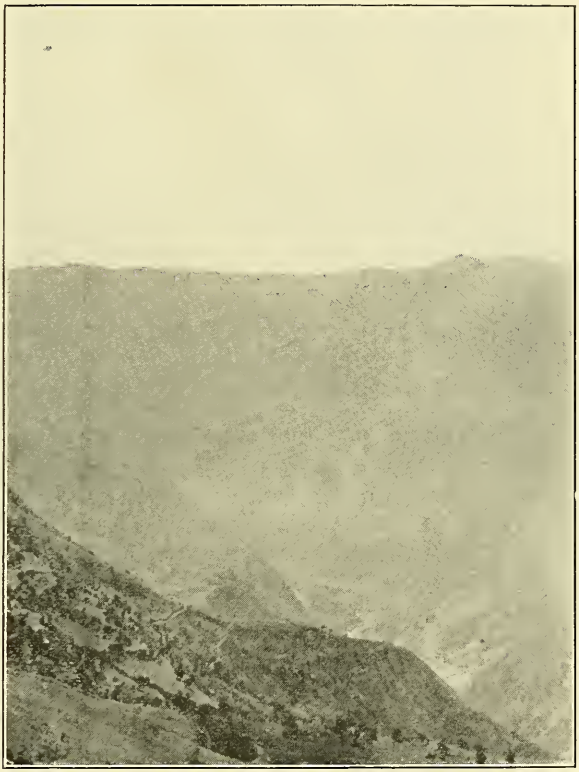


FIG. 5. View from the Pass at the southern edge of the Ayusbamba fossil beds, looking south into the Apurimac canyon. Note the rock and alluvial terraces.

sent both rounded bosses and sharp arêtes,—features characteristic of glaciated surfaces. Summits below 12,300 feet assume forms consistent with the rôle which they play as part of a submaturely developed landscape. Along the highland trails north from Ayusbamba and also east toward Paruro irregularly distributed erratics, incipient cirques, bowlder trains, and

interrupted drainage speak of a widespread glaciation which has substantially modified the pre-Pleistocene topography.

The bedrock of the whole region between the Apurimac and Cuzco valleys is brown and grey sandstone, whose continuity of stratification is interrupted by lenses of conglomerate and occasional beds of shale. The sandstone strata rarely approach horizontality; dips of 20°–40° are common, and where exposures are favorable these tilted strata are seen in folds open or closed, and with horizontal or steeply inclined axes. Near the headwaters of the Mollemolle exposures of dense blue-grey limestone, much fractured and in places brecciated, roughen the hill-slopes. This rock, in common with the sandstone, appears to be identical in lithologic character with the strata represented in the Huatanay valley, and the single fossil (Lower Cretaceous) obtained from the limestone is a duplicate of many collected at Cuzco. The Lower Cretaceous limestone overlies strata of sandstone of great extent and more than 1000 feet in thickness. The relations existing between the calcareous and arenaceous beds have not been determined. Strata containing carbonized plant fragments and unconformably overlying the brown sandstone were found near the village of Paruro, and assigned by Dueñas* to the Tertiary. The reasons for such a conclusion are not given, and so far as the writer is aware the only paleontologic evidence of age relations consists of a Lower Cretaceous lamellibranch, and the vertebrate remains from Ayusbamba described by Dr. Eaton.

With the exception of intrusives cutting the Apurimac canyon wall, no igneous masses were observed, although, as stated below, it is probable that a boss of diorite lies buried beneath the superficial deposits at Ayusbamba. Dueñas found that diorite intersected by dikes of red and green labradorite containing phenocrysts of augite was associated with the everpresent grey and brown sandstone at several localities in the province of Paruro.

The discovery of coal in the vicinity of Paruro has from time to time been announced. The basis for such reports is doubtless the presence of carbonized wood and lenses of impure lignitic peat which occur among the strata of ancient lake beds. My observations are in accord with the results of a reconnaissance conducted by Peters and Company, and with the conclusion of Dueñas, that the quantity of the so-called "coal" is negligible and its quality unsatisfactory. Rock for building, lime for cement, and excellent clay, all of which may be obtained in quantity, complete the list of rocks of economic value in the Ayusbamba region.

* Boletin Cuerpo de Eng. de Min. del Peru, No. 53, 1907, p. 122.

The Ayusbamba Lake Area.

General relations.—The Ayusbamba lake deposits cover an area of about one-eighth of a square mile (see map, fig. 8), situated in an unusual position, at the top of the pass traversed by the trail from Ccoypa in the Mollemolle valley to Bilcokyma, a tiny pueblo perched on a terrace within the Apurimac canyon. The depression containing the fossil beds is walled in on the east by sandstone ridges rising 800′ above the center; the ledges forming the west border are deeply buried in superficial débris. At the north the lacustrine deposits are abruptly ter-

Fig. 6.

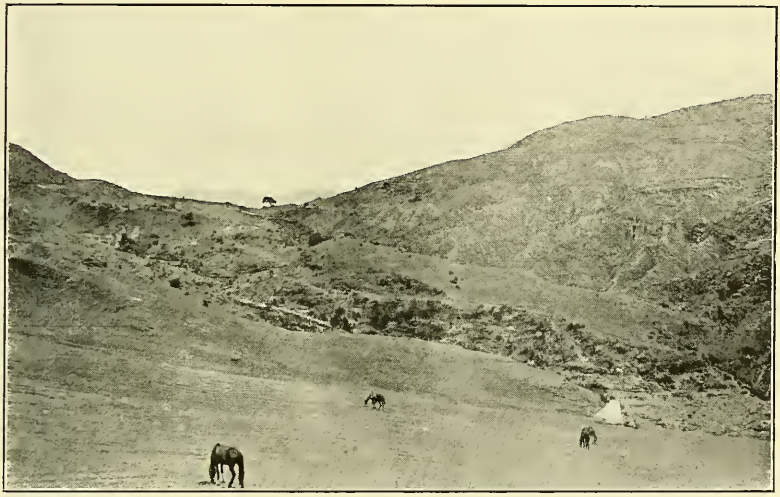


Fig. 6. View of Ayusbamba fossil beds, looking south-southwest, toward the pass into the Apurimac valley. Note the attitude of the strata.

minated by a steep slope developed by vigorous headward erosion of a tributary to the Chipura. Fringing the rock borders on the west, south, and east are slopes of surface wash and fans more or less dissected, which in turn overlap the clays of the central part of the depression.

The surface of the lacustrine deposits (fig. 6 and map, fig. 8) slopes northwestward, and the streams which drain the area unite to form an outlet channel which, after passing through a narrow, vertically walled gorge 30 feet deep, makes an abrupt descent by a series of rapids and waterfalls to join the Chipura and finally the Apurimac. A much shorter course with much

steeper gradient,—a course leading south directly to the Apurimac,—is being established by headward erosion, and the divide has migrated eastward within recent times (fig. 7).

Dissection of the lacustrine beds has been accomplished by Calvo brook,* consisting of two streams which unite to form the main outlet channel. The valley of Calvo brook presents youthful features both along its larger branches and in the innumerable tiny canyons cut in clays and sands. About one-third of the interstream spaces consists of imperfectly

Fig. 7.

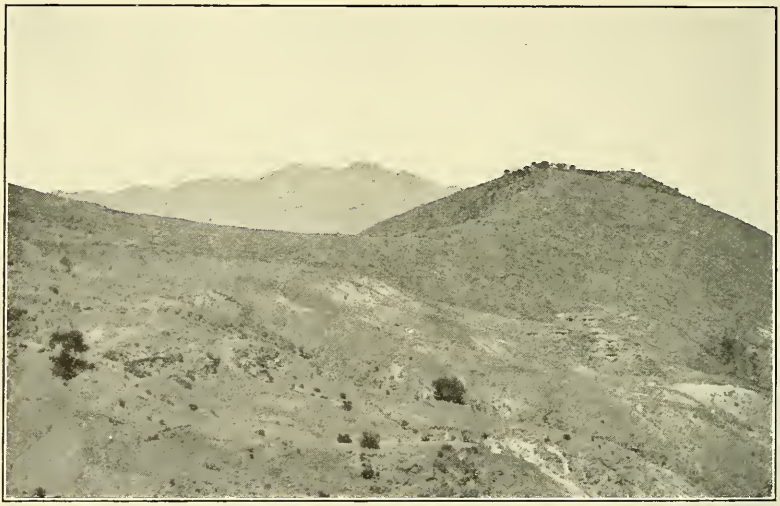


Fig. 7. View of fossil locality, looking southwestward across the divide between Calvo brook and the Apurimac river. The divide is migrating toward Calvo brook. Photograph by G. F. Eaton.

drained grass plats; the remaining portion is marked by "bad land" slopes and mounds cut by canyons 30–40 feet deep, two to ten feet wide, producing a surface difficult to traverse. Surficial erosion is augmented by numerous springs and seeps, emerging at the contact of clay and sand. Landslides are of frequent occurrence and greatly facilitate the removal of the lacustrine deposits. Ancient corrals and andenes point to former human occupation, and their position shows that a considerable part of the tillable land has been lost through recent stream erosion.

* The liberty has been taken of naming this stream in honor of Señor Emeterio Calvo, the hospitable proprietor of hacienda Ayusbamba.

Bed rock.—The lake beds at Ayusbamba rest on sandstone coated with a layer of coarse bowlders and followed upwards by clays, sands, ash and peat, above which, near the edges of the basin, are unstratified angular gravels distributed as fans and surface wash. The rock floor is exposed on the north and on the south rims of the basin and in the beds of several of the minor stream branches. The bed rock is essentially sandstone, brown or grey in tone, especially on weathered surfaces. The strata, which vary from 6 inches to 20 feet in thickness, rarely maintain their individuality for more than 100 feet along the strike, and may be considered as a series of lenses whose dimensions and texture are subject to abrupt changes. Angular cross bedding is a noticeable feature in the medium-grained sandstone, and sun-baked surfaces were observed on the bedding planes of the shaly limestone. A number of minute faults were noted.

While the rock ledges underlying and surrounding the ancient lake basin may roughly be grouped as sandstones, there is considerable variation in texture and composition as indicated by the following rock types represented:

(1) Sandstone, very fine, even-grained, composed of quartz grains of microscopic size embedded in silicious cement.

(2) Sandstone, medium to coarse-grained, consisting of subangular and angular fragments of white quartz, feldspar crystals, diorite-porphyry, sandstone, and rare limestone; bound together by silica.

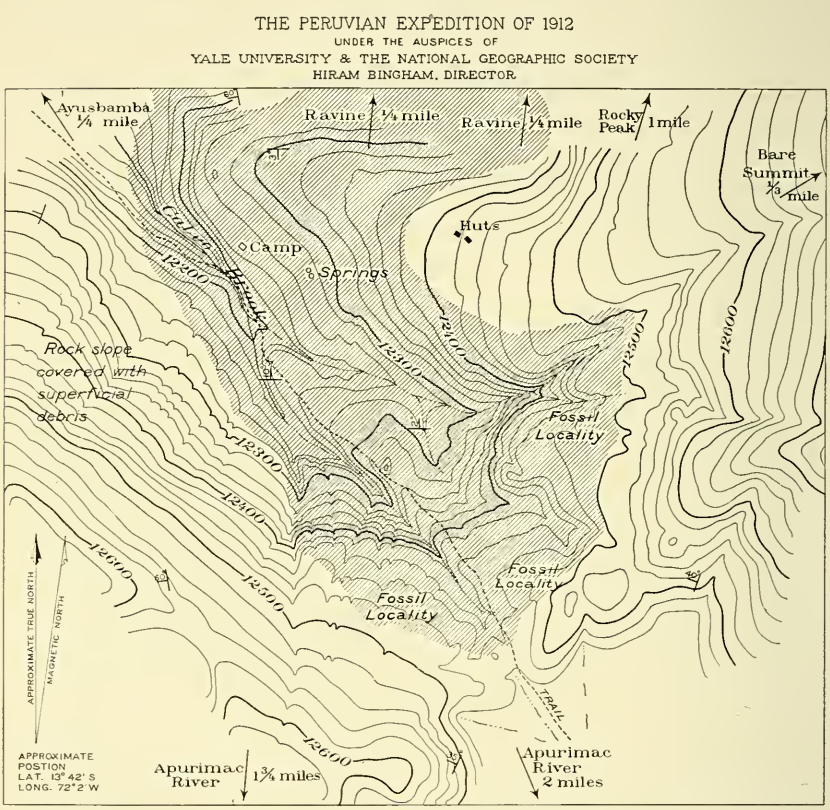
(3) Thin lenses of purple-brown, arenaceous, shaly limestone.

(4) Conglomerate with pebbles the size of buck shot and upwards.

The finer-grained phases of the conglomerate grade into sandstones and consist of the same materials; but in the ledges facing the Chipura the pebbles are larger (1/4″ to 3″ in diameter; one dacite bowlder measured 2′), and are distributed as broken strings or as individuals embedded in a cubic foot or cubic yard of sandstone matrix. The larger pebbles composing the conglomerate at this locality include quartzite, biotite-granite with orthoclase phenocrysts and a dark grey igneous rock with granitic and porphyritic facies. The last-named rock which is not only a constituent of the conglomerate but is present in the overlying bowlder bed and occurs in fragments of various sizes dotting the surface southwest of the hacienda buildings, is worthy of special notice. A hand specimen of this rock is seen to consist essentially of crystals of hornblende, $\frac{1}{8}''$ to $\frac{1}{2}''$ in length, embedded in a groundmass of crystals of microscopic size. A few pyroxene crystals are also present as phenocrysts. Microscopic examination of the

groundmass reveals the presence of plagioclase feldspar, biotite and magnetite in addition to much hornblende and a limited amount of pyroxene. Fragments of calcite and of an undetermined zeolite were observed in one of the three sections

FIG. 8.



MAP OF A PORTION OF THE PROVINCE OF PARURO, PERU
SHOWING FOSSIL LOCALITY NEAR AYUSBAMBA

Topography by K. C. Heald and Carlos Duque
Geology by Herbert E. Gregory

Contour interval 20 feet. Datum sea level (levels brought from Cuzco by aneroid)

Shaded area indicates Lacustrine deposits

examined. The rock is therefore to be classed with dioritic or andesitic porphyries. The relative abundance and localization of these diorite bowlders suggest the possibility that an intrusive mass now covered by superficial débris exists to the west of Calvo brook.

The structural relations of the sandstones were not studied in sufficient detail to permit of a definite statement regarding

their origin and conditions of deposition. However, the irregularity of bedding, the abrupt change in composition and texture along strike, the predominance of subangular bowlders, the type of cross bedding, the presence of sun-baked surfaces, and the brown color of the rock suggest continental rather than marine sedimentation.

Bowlder Bed.—Directly overlying bed rock and immediately beneath lacustrine clays and sands, a bowlder bed is exposed at a few localities. The pebbles, all subangular, are chiefly igneous, and include the following varieties: Andesite, dense and scoriaceous; diorite-porphyry; granite-porphyry; rare granite; black and green hornstone; black, pink, and gray quartzites; brown and red sandstones. About eighty per cent of the bowlders measure between one and six inches; the largest seen in place is four feet in diameter, although larger blocks are embedded in the banks of Calvo brook. In places the bowlder bed is loosely compacted; elsewhere so firmly cemented that pebbles may be broken without disturbing the matrix. The exposures of bowlder bed studied gave no certain clue as to origin. The heterogeneous character of the mass, both as regards composition and stratification, suggest morainal accumulations, yet striated bowlders and scoured floor were not observed. Part of the material might well have been supplied as talus, but with the exception of sandstone fragments the bowlders are of types not represented in the country rocks. The history of the bowlder beds cannot be written on the basis of present knowledge of the Apurimac valley region.

Lacustrine Beds (Map, fig. 8).—The lake beds proper—clay, fine sand, ash, and peat—rest in some places upon the bowlder bed; elsewhere directly upon the sandstone floor. The strata dip slightly toward the center of the basin, but with many variations and exceptions. The northward dip is in general greater and suggests a tilting of the beds at a time postdating their deposition. The stratigraphic succession of the lacustrine beds is shown in the following selected sections:

Section I. West branch Calvo brook.

200′ from junction. Dip of clay beds NE ∠ 10°.

	Feet
1. Grass-covered slope of superficial debris	3
Unconformity.	
2. Sand, fine, with lenses of coarse sand and of adobe, containing plant roots; a few thin clay layers	30
3. Volcanic ash, excessively fine, soft, pure white, regularly stratified in beds about one-tenth of an inch thick	1

4.	Sand, fine, even-bedded, thin-bedded, with four strata of pink clay (aggregating 3′) composed of layers about one-fiftieth of an inch thick	13
5.	Sand and clay like No. 4 in alternating beds. Includes a lens 1″ thick, 50′ long, of black iron-cemented sand,	10
6.	Clay, brown, thin, even-bedded, and fine sand. Few bone fragments. Total clay about 60 feet; sand 35 feet	95
7.	Coarse sand, firmly cemented, forms bench	0·3
8.	Sand, fine, thin-bedded	10
9.	Sand, fine, containing three lenses and one 3″ bed of sand and clay firmly cemented by lime and containing abundant bone fragments	6
10.	Sands, fine, thin-bedded, with small amount of clay	15
		183·3

Section II. East branch Calvo brook.

100 feet from junction.

		Feet
1.	Soil,—brown, mixture of gravel and sand	15
2.	Sand and fine gravel, containing numerous carbonized fragments of plants	3
3.	Peat, brown, porous, mixed with mud; plants too fragmentary for determination	0·25
	Unconformity.	
4.	Gravel, composed of angular pebbles one-half inch to four inches in diameter	1·5
	Unconformity.	
5.	Sand, with small amount of thin-bedded clay, yellow, traversed by carbonized roots and root-tubes; probably an old soil	3
6.	Clay, light brown; and sand, fine, clear, in alternate, very thin strata. Clay and sand about equal in amount	30
		52·75

Section III. West branch of East branch of Calvo brook.

Dip N∠ 2°.

		Feet
1.	Gravel, and sand; surface wash	5
2.	Gravel and fine sand, grey; loosely cemented by iron.	2
	Unconformity.	
3.	Clay, very thin, even layers, forming strata three inches to one foot thick, which alternate with strata of fine sand. A few decomposed bones	10
4.	Volcanic ash, white, microscopically fine-grained, thin-bedded, porous. Locally called "chalk"	1·5
5.	Clay and sand, very thin layers grouped in alternate strata	8
		26·5

Notes on measured sections.—The individual clay beds are nowhere thick and at all places are interbedded with fine sand. At the north edge of the basin, where 135 feet of lacustrine deposits are exposed, the section consists of alternating layers, one-tenth of an inch to four inches thick, of fine sand and banded, dark red clay in the midst of which occur three lenses of coarse sand. The layers of sand and clay interleave as lenses fifty to two hundred feet long. Minute folds and faults further interrupt the regularity of bedding. The clays are red, pink, or brown in tone, due to their content of ferric iron in hydrated form, and are believed to owe their origin to the decomposition of the surrounding pre-Cretaceous sandstones. No "clay dogs" or concretions were observed, but a few small, light-colored patches in the clays are highly calcareous in marked contrast to the clay in general. Apparently the process of segregation is in operation at the present time.

The regularly banded white ash, interstratified with the clays, decomposes under slight pressure to an impalpable powder which has a gritty "feel." Microscopical study of this rock revealed the presence of glass arranged as threads and cusps and hooks, and constituting about 90 per cent of the mass; laths of plagioclase and frayed ribbons of biotite complete the list of component minerals, and determine the classification of the deposit as dacitic ash.

No true peat or coal was found among the beds, but at several localities thin bands of an earthy mixture of sand, clay, and vegetable fragments were noted. This mixture was found by microscopic examination to consist of minute shreds of glass, tiny feldspar, quartz, biotite and muscovite fragments, together with broken bits of volcanic ash and portions of calcite crystals. The plant remains present were too fragmentary for determination.

The remains of vertebrates are found among the upper gravels, on floors of tiny ravines, and embedded in clay or sand layers. The content of the calcareous sand lenses (No. 9, Section I), commonly a mixture of sand, lime, and clay, is in places fully one half bone fragments. Bones are widely scattered horizontally, and in a given locality may be found unrelated parts of a skeleton mingled with bones of animals belonging to entirely different species. No entire skeletons were found in place, and it is probable that several feet of strata intervene between portions of the same carcass. The species represented by parts of skeletons are listed and described by Dr. Eaton (pp. 144-154 following). Field evidence justifies the conclusion that bones of animals which died on shore or floundered in bogs or quicksand were redistributed by surface wash and running water.

Origin and character of Lake Ayusbamba.—From the sections and descriptions given above it is evident that we are dealing with deposits which in part are truly lacustrine,—material laid down in a body of quiet water which existed for a relatively long period of time. On the assumption that each layer of sand and of clay represents the amount deposited during a single rainy season, approximately 100,000 years would be required for the accumulation of the materials exposed in the present fragmentary sections. It is probable that the lake beds had greater thickness. That they formerly extended much farther northward is shown by an unprotected, truncated section including 185 feet of strata perched high on the valley side overlooking the Chipura river. The containing wall of rock is complete except on the north side, where it has been entirely removed. Unlike the remaining portions of the rim, the north wall probably consisted of fluvial and glacial débris washed from the highlands. Moraines extend to the edge of the present lake deposits and may have formed the original barrier. During the life of the lake, fans from the high ridge at the south encroached upon its waters and separated the original sheet into more or less detached bogs. This process, combined with the development of a channel through the unconsolidated northern barrier, led to the extinction of the water body. Judging from the physical data at hand, this mountain tarn may have beautified the landscape of the late Pliocene or any portion of the early Pleistocene epoch,—a conclusion which is in harmony with the paleontological evidence.*

Ancient Lake Ayusbamba is not an isolated case of extinct water bodies in Peru. Dueñas† speaks of similar deposits near the pueblo of Paruro, and the unpublished reports of engineers and travelers indicate the existence of unexplored Tertiary and Pleistocene deposits scattered over the Andean highlands.

* See the following article by Dr. George F. Eaton, pp. 141 to 154.

† Loc. cit.

Art. IX.—*Vertebrate Fossils from Ayusbamba, Peru;* by George F. Eaton.* With Plates V, VI, VII.

While engaged upon the field-work of the Peruvian Expedition of 1912, I had the pleasure of accompanying Dr. Albert Giesecke, President of the University of Cuzco, on a hasty visit to a locality near Ayusbamba, among the mountains about thirty miles south of Cuzco, where he had previously obtained some fragmentary vertebrate fossils. On this occasion a few hours only could be spent in the field; but as it seemed probable that by going over the ground carefully, further material might be secured, Professor Bingham, the Director of the Expedition, gave his consent to my making another visit to the locality, this time in company with Professor Gregory, the geologist, Mr. K. C. Heald, assistant topographer, and Mr. C. Duque. Although other important work caused the postponement of this trip until the middle of November, when the rainy season, unfavorable to fossil-hunting in the mountains, had set in, we were able to obtain material of considerable value during the brief time our party was in the field. To Sr. Emeterio Calvo, the master of the delightful hacienda Ayusbamba, I owe my sincere thanks, not only for permission to collect upon his land, but also for the generous hospitality extended to our party.

The fossils that form the subject of these notes occurred at an altitude of about 12,400 feet, in gravel and clay beds and in surface-wash along the southern margin of a small lake, the original contours of which are partially indicated in the map (fig. 8) accompanying the preceding article by Professor Gregory. An excellent view, looking southerly across the fossil grounds, appears as fig. 6 of Professor Gregory's report. Very nearly the reverse view (N. 5° E. Mag.) taken from the south rim of the basin, is shown in text-figure 1 of the present article. After taking this photograph the camera was turned a little to the right (N. 30° E.) and the view shown in text-figure 2 was taken. These two views together cover practically all of the fossil grounds. Almost at the exact center of Professor Gregory's fig. 6, a mastodon's blade bone was found. The nearer view of this spot (text-figure 3) is equally characteristic of several other places where fossils occurred. In this photograph, taken while waiting for the protective jacket of burlap and plaster to dry, appears one of our faithful arrieros whose interest in collecting fossils made him very helpful.

With few exceptions, fractured and dissociated material only

* Osteologist of the Peruvian Expedition of 1912.

was found. This indicates clearly that, in most cases, the bones of animals, perishing near the borders of this ancient lake, were widely scattered before being finally covered by alluvium from the neighboring heights. It is possible that

Fig. 1.

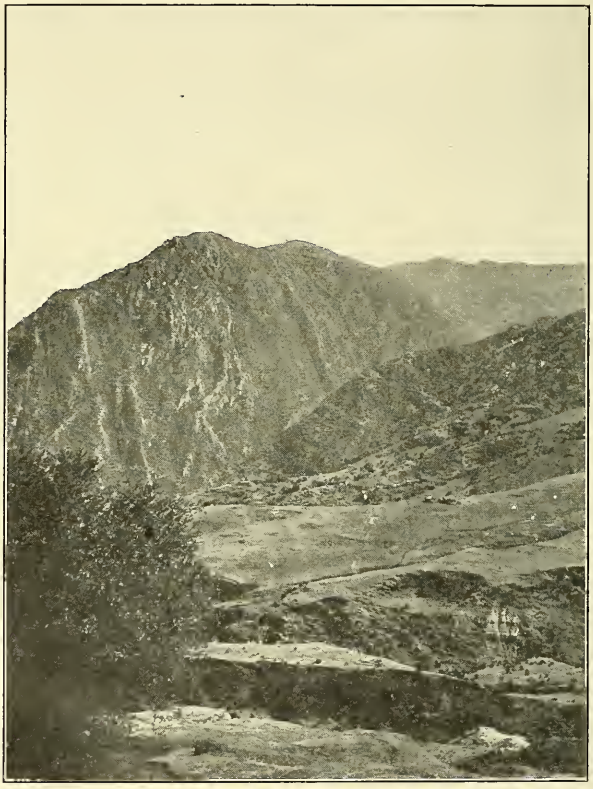


Fig. 1. View N. 5° E. over Ayusbamba fossil beds from the southern margin of the basin.

some of this vertebrate material may have been originally embedded at a slightly higher level. I see no reason, however, to question the contemporaneity of the extinct species of animals represented in this collection. No vertebrate fossils had been previously described from this part of the Peruvian Andes. Therefore every recognizable specimen, that might add to our

knowledge of the extinct fauna of the region, was collected, without regard to its perfection and availability for exhibition. Nearly all of this material has now been identified, and it is found that specimens can be referred to five mammalian

Fig. 2.

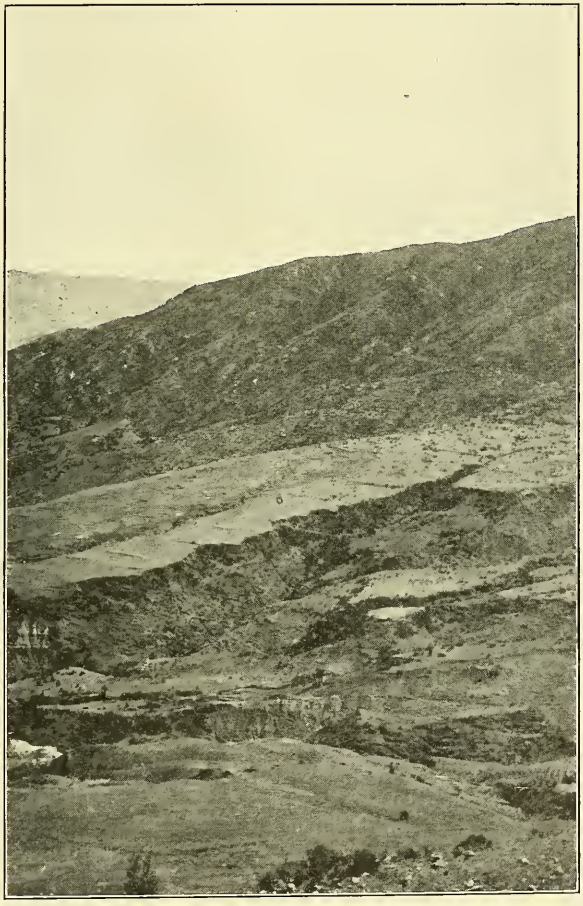


Fig. 2. View N. 30° E. over Ayusbamba fossil beds from the southern margin of the basin.

families, the Camelidæ, Cervidæ, Equidæ, Elephantidæ, and Mylodontidæ. No fossil remains of Rodents and Carnivores were observed. The material may be assigned to the following genera:

Lama sp.

The fifth lumbar vertebra and portions of the right ilium and ischium. The specimens compare closely with the corresponding skeletal parts of a medium-sized animal of the recent species, *Lama huanachus*. It is, of course, impossible to assign the present specimens definitely to any one of the several species of this genus that have been described from the Pliocene and Pleistocene of Argentina and Brazil.

Fig. 3.

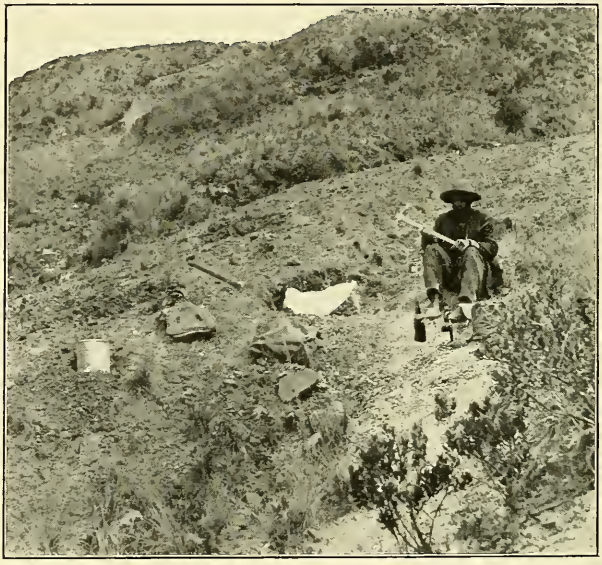


Fig. 3. A mastodon's scapula ready for removal, Ayusbamba.

Odocoileus brachyceros.

The material from Ayusbamba referable to this genus and species includes a fifth cervical vertebra belonging to an animal considerably smaller than a full-grown Virginia deer, and also a number of fragments of antlers, picked up on the surface of the lake-beds. Fortunately the basal portion of one of the antlers has been preserved. No upright snag rises from the base of the inner side of the beam, and the antlers fork near the burr, the basal portion being extremely short. These characters, together with the texture of the surface, serve to identify the Ayusbamba specimens with *Odocoileus*

brachyceros as defined by Professor Lydekker,* who states: "It does not appear that this deer comes close to any existing species."

Philippi has caused some confusion by giving the name *Cervus brachyceros* to three individuals of the Venado de Cajamarca, which he proposed to separate, under this name, from the recent species of Andean deer, *Odocoileus antisiensis* = *Cervus antisiensis.*† It is apparently far from Philippi's intention to convey the idea that the Pleistocene *Odocoileus brachyceros* has persisted until the present time. The antlers of this fossil species are quite different from those of the recent deer to which a similar specific name has been thus unfortunately assigned.

Dibelodon bolivianus.

Remains of *Dibelodon* were the most abundant fossils at Ayusbamba, bones and teeth, usually dissociated and incomplete, occurring at various places in the beds of clay and gravel, and also superficially. It is significant of the history of these deposits that only small and compact bones should have been preserved entire. The individuals of the species, whose remains were found here, differed considerably in size, and it appears from the dentition and from the condition of the epiphyses that many of these animals had not attained their full growth. An accurate comparison of their mature size with that of other mastodons cannot therefore be made. The maximum stature indicated by the largest bones is not more than three-quarters as great as that of the medium-sized example of *Mammut americanum*, whose mounted skeleton is exhibited in the Peabody Museum of Yale University. The height of this animal, taken at the shoulder, is about 8 feet and 3 inches.

Of the six South American species of *Mastodon* described by Ameghino,‡ the two most generally recognized are *M. andium*, Cuv., and *M. humboldti*, Cuv. According to Pompeckj§ there are two other valid species, namely, *M. bolivianus*, Philippi (emend. Pompeckj), and *M. chilensis*, Philippi. While Pompeckj does not adopt Cope's separation of *Dibelodon* and *Tetrabelodon* from *Mastodon*, it should be understood that both *M. bolivianus* and *M. chilensis*, as well as *M. andium* and *M. humboldti*, belong to the Dibelodont division of the original genus.

* Paleontologia Argentina, II, p. 79.

† Anales del Museo Nacional de Chili, 1894, Entr. 7, Primera Seccion, p. 5.

‡ Mamiferos Fosiles de la Republica Argentina.

§ Mastodon-Reste aus dem inter-andinen Hochland von Bolivia. Palæontographica, vol. lii, 1905.

Most of the mastodon bones found at Ayusbamba present no characters that can be utilized in the identification of the species. As might be expected, it is best to rely principally upon the form and structure of the teeth. Two specimens have therefore been selected to illustrate the type of dentition. From the piece of a right (upper) tusk shown in Plate V, figures 1 and 2, the following measurements have been taken:

Circumference of proximal end	354^{mm}
Breadth of enamel band	90
Maximum diameter at proximal end	117
Minimum diameter at proximal end	104
Angle of torsion	12°

The last of these measurements requires a few words of explanation. A mastodon's tusk upon which the enamel band, or other line of growth, describes a helix, presents a certain analogy to a screw; and the torsion of such a tusk may properly be regarded as a pitch angle. The angle of torsion, used here, is defined as the angle that a tangent to the spiral enamel band, at any point, makes with the adjacent axial line of the tusk. This measurement is easily taken. It has the further advantage of being independent of length, diameter and circumference; and may prove to be of considerable taxonomic value. The mere statement that an enamel band makes one revolution, or one-half revolution, about the axis, without any record of length and diameter, does not adequately describe the torsion.

The form of the tusk of *M. bolivianus* is described by Pompeckj* as follows: "Der Querschnitt ist vollkommen elliptisch; die Durchmesser sind an der hinteren Bruchfläche 8·9 : 6·2^{cm}, an der vordere 6·2 : 4·7^{cm}. Das z. T. abgefallene Schmelzband hat vorne eine Breite von 5·65^{cm}." In another place† he compares this tusk with that of *M. andium*: "Die schlanken, sehr wenig gekrümmten, in Schraubenspirale von ungefähr 1/2 Windung gedrehten Stosszähne haben bei *Mastodon bolivianus* stark komprimierten elliptischen Querschnitt, nicht den kreisrunden der Zähne von *Mastodon Andium*."

That the enamel band is very broad in *M. bolivianus* is evident from Pompeckj's measurements of the anterior portion of a tusk and also from his illustration of a basal fragment,‡ where the enamel appears to cover one-third of the circumference. The band is a trifle narrower in the fragment of tusk from Ayusbamba, which differs also from *M. bolivianus* in the ratio of the maximum and minimum diameters. To comply with the diametric ratio (8·9 : 6·2) obtained from *M. bolivianus*, the

* Op. cit., p. 38.
† Op. cit., p. 44.
‡ Op. cit., Taf. IV, Fig. 56.

Ayusbamba specimen having a maximum diameter of 117^{mm}, would require a minimum diameter of only 82^{mm}, instead of 104^{mm}, as recorded. Yet its section, as shown in fig. 5, is still very far from circular, and cannot be described by the same terms that Pompeckj uses in reference to the tusks of *M. andium*. The tusk of the latter species, figured by Ameghino,* greatly exceeds the Ayusbamba specimen in diameter, and possesses an enamel band relatively much narrower. Its curvature and the angle of torsion of the enamel band are approximately the same as those of the Ayusbamba specimen. The torsion of the tusk of *M. bolivianus* is not recorded in such a way as to be available for comparison.

Views of the grinding and labial surfaces of an unworn molar from Ayusbamba are shown in Plate V, figures 3 and 4. This tooth, imperfect anteriorly, is presumably a lower molar of the left side. Large accessory tubercles rest like buttresses against the outer columns, but the tubercles that flank the inner columns, and those that lie in the depths of the inner valleys, are so small as to be almost hidden beneath the thin layer of cement. As a result of this arrangement, the tooth would be characterized, during early stages of wear, by the presence of trefoils on the outer columns only, while the inner valleys would remain open. Although this tooth agrees, in the foregoing characters, with the specific definitions of *M. andium* given by Lydekker† and by Ameghino in his work already cited, the correspondence fails entirely when the contours of the inner columns are considered. Lydekker states that "The form of the dentine-disk on the columns which do not bear trefoils is pear-shaped, with the apex directed toward the adjacent column." The inner columns of the Ayusbamba molar are as stout where they approach the median cleft as at their lingual borders, and would not, at any stage of wear, assume a pear-shaped outline. In view of this essential difference, I do not think that the Ayusbamba molar should be referred to *M. andium*. It compares much more closely with the lower molar of *M. bolivianus* figured by Pompeckj.‡ The small accessory tubercles that flank the inner columns and line the inner valleys of this tooth find their counterparts half-concealed beneath the cement layer of the Ayusbamba molar. The transverse measurements of the tooth of *M. bolivianus*, taken at the base of the crown, viz., for the 1st cross cusp 7·4^{cm}, for the 2nd 7·75^{cm}, for the 3rd 8·0^{cm}, for the 4th 7·8, for the 5th 7·4^{cm}, correspond very nearly with the following transverse measurements taken in the same way from the Ayusbamba

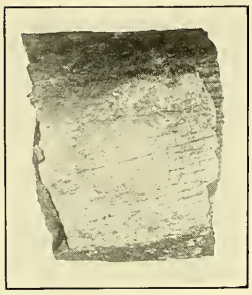
* Mam. Fos. de la Repub. Argent., p. 640.
† Cat. Foss. Mam. Brit. Mus., 1886.
‡ Op. cit., Taf. III, Fig. 1a.

molar: for the first cross cusp 7·3^{cm}, for the 2nd 7·4^{cm}, for the 3rd 7·2^{cm}. Taking into consideration the characters of this molar tooth and also those of the fragment of tusk, previously described, I am confident that both of these specimens should be referred to *Mastodon bolivianus*, or *Dibelodon bolivianus*, if it is best to use the generic name proposed by Cope.

It is not surprising that remains of this species should be found at Ayusbamba, for Ulloma, where the type material of *D. bolivianus* was obtained, is less than 350 miles distant, being situated at an altitude of about 3,800 meters, in the high Bolivian table-land south of Lake Titicaca. There seems to be no reason to doubt that the same climatic conditions prevailed in these two localities during the early Pleistocene.

Mylodon sp.

The Gravigrade Edentates hold such an important place in the Pleistocene fauna of South America, and have been so closely associated, in their distribution, with the Elephantidæ and Equidæ, that one might expect to find the group represented in the collection from Ayusbamba. Vertebræ, pieces of the ribs, including an ossified sternal section with its characteristic double articulation, and an ungual phalanx, from this locality, should be referred provisionally to the genus *Mylodon*, so closely do they resemble the corresponding parts of the mounted skeletons of *M. robustus* and *M. myloides* in the American Museum of Natural History. I have no means of determining the species. In this connection may be mentioned a humerus of *Mylodon* that was found, not at Ayusbamba, but within two miles of Cuzco, where the road to Ayusbamba ascends from the Huancaro Valley. The location of the bone beneath well-defined beds of fine and coarse alluvium, about 28 feet in thickness, is marked in text-figure 4 by the point of an arrow. This humerus, shown in Plate V, figures 5 and 6, differs from the humeri of *M. robustus* and *M. myloides* at the American Museum in not having so prominent a deltoidal tract. The outer tuberosity is also smaller, and the posterior outline, immediately below the head, is more deeply concave. These differences, while slight, are sufficient to indicate that some species of *Mylodon* other than *M. robustus* and *M. myloides* occurred in this part of the Cordillera. Potsherds and bones of llamas were observed at a depth of 2½ feet in the surface stratum at the top of the bank where this humerus was found; but no objects were seen in the lower strata that could, in any way, associate the *Mylodon* bone with the period of human inhabitation.



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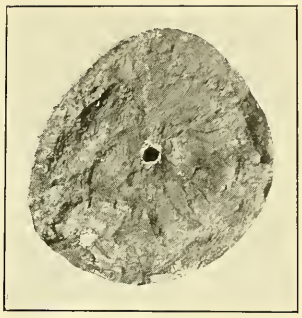

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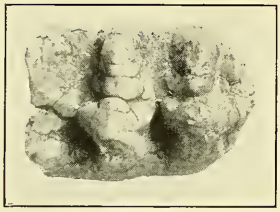

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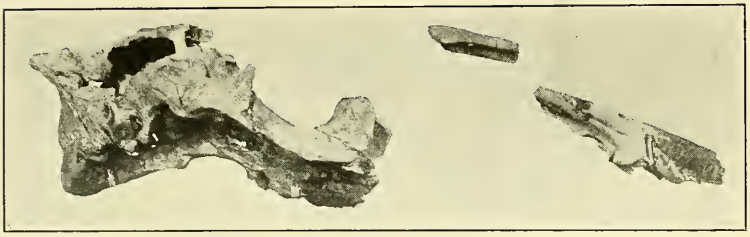
FIG. 1. *Dibelodon bolivianus*, fragment of right tusk. × 0·26.
FIG. 2. The same fragment, proximal end. × 0·29.
FIG. 3. *Dibelodon bolivianus*, left lower molar. × 0·29.
FIG. 4. The same tooth, labial surface. × 0·26.
FIG. 5. *Mylodon* sp., right humerus, anterior view. ×0·25.
FIG. 6. The same specimen, external view. × 0·25.



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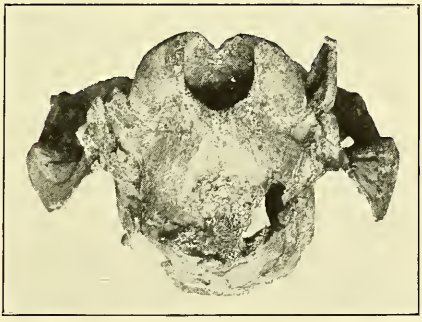

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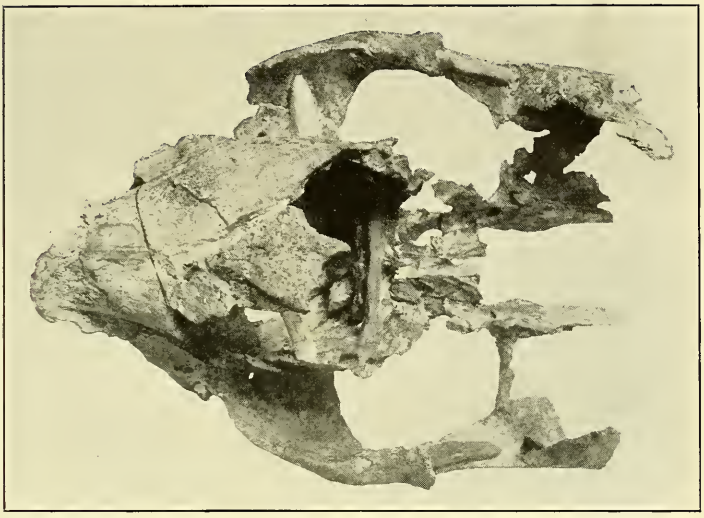
Fig. 1. Skull of *Parahipparion* sp., from Ayusbamba, lateral view. × 0·18.
Fig. 2. Skull of *Onohippidium compressidens* in the Museum of La Plata, after Lydekker. × 0·15.
Fig. 3. Skull of *Parahipparion* sp., from Ayusbamba, posterior view. × 0·25.



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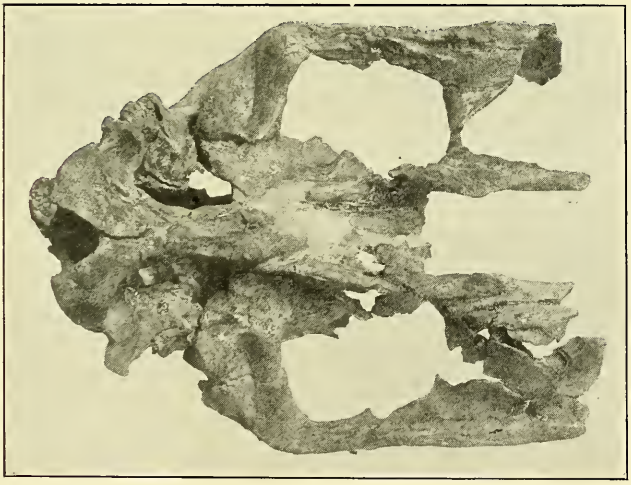

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Fig. 1. Skull of *Parahipparion* sp., from Ayusbamba, superior view. × 0·30.

Fig. 2. Skull of *Parahipparion* sp., from Ayusbamba, inferior view. × 0·28.

Parahipparion.

Equine remains collected at Ayusbamba include several teeth, a fragmentary skull and a portion of the distal end of a femur. The teeth were all surface specimens, and there was nothing about the manner of their occurrence to prove that any of them belonged to the same individual as the skull. Two of

FIG. 4.

FIG. 4. Location of *Mylodon* humerus (indicated by arrow-point) by the side of the road from Cuzco to Ayusbamba.

them, however, may be from one individual, not necessarily because they were picked up within a few rods of each other, but because they show equivalent structure, size and stage of wear. These two teeth, first and second functional lower

cheek teeth (p_2 and p_3) are accordingly represented together in text-figure 5. Owing to their imperfection exact measurements cannot be taken; but the length and width of their crowns appear to have been approximately as follows: p_2, length 29^{mm}, width 14·2^{mm}; p_3, length 27^{mm}, width 16^{mm}. These dimensions and the pattern of the enamel foldings show that the teeth cannot be referred either to *Equus curvidens* or to any of the three species of *Hippidium* whose teeth have been minutely described and figured by Sefve.* Their affinity lies rather with the genus *Parahipparion*. In view of the difficulties that beset the study of isolated equine teeth, especially those of the lower series, it would perhaps be unwise to attempt the specific identification of these two lower premolars; but it is significant that among all the teeth with which they have been compared, they most nearly find their counterparts in the first and second lower deciduous molars, and the first molar, of *Parahipparion peruanum* from Tirapata, Peru, figured by Sefve.† The united length of the first two milk molars of this last mentioned specimen amounts to approximately 56^{mm}; and this measurement exceeds the restored united length‡ of the two teeth under discussion by 2^{mm}, which is very nearly the difference in length that one might expect to find between the first and second lower deciduous teeth and their permanent successors. So many variable and uncertain factors enter into these measurements that the comparison should not be carried too far.

In another lower cheek-tooth (p_2) from Ayusbamba the forms of the inner valleys (text-figure 6) are simpler than in the teeth last described, the contrast in this respect being almost too marked to be readily accounted for by the fact that the teeth present different stages of wear. It should be noted that the teeth shown in text-figures 5 and 6 possess, in common, a very deep outer valley that penetrates between the inner valleys and nearly traverses the crown. The deepening of the outer valley, according to Sefve's observation, characterizes *P. devillei* and *P. peruanum*, and distinguishes them from *P. saldiasi*. The premolar of text-figure 6 measures, on the crown, 29^{mm} x 14^{mm}. In its enamel pattern, as well as in its size, it is remarkably like the p_2 of *P. devillei*,‡ which has a length of 28^{mm} and a width of 13^{mm}. Although the species of the Ayusbamba specimen is not determined by the above com-

* Die Fossilen Pferde SüdAmerikas; Kungl. Svenska Vet. Hand., 1912, Band 48, No. 6.

† Hyperhippidium; Kungl. Svenska Vet. Hand., 1910, Band 46, No. 2, Taf. 2, Fig. 4.

‡ The united length of overlapping teeth is less than the sum of their individual lengths.

‡ Sefve, 1912; Taf. 2, Fig. 21.

parison, there is no doubt that it belongs under the genus *Parahipparion*.

Examination of an upper molar (text-figure 7) leads to about the same conclusions as were obtained from the study of the lower teeth already described. This tooth appears to be either the first or the second upper molar of the right side. Probably it is the first. The length is 21·5^{mm} and the width 22^{mm}. The depth of the crown is greatly reduced, only about 30^{mm} of the prism being left. In fact, it is so low as to present an almost senile stage of wear. Under these circumstances not only would the pattern of the enamel foldings be simplified,

FIG. 5. FIG. 6. FIG. 7.

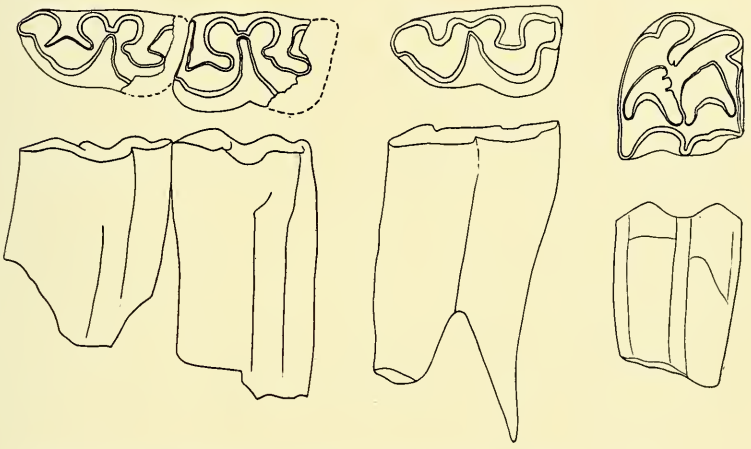


FIG. 5. Pm_2 and Pm_3, *Parahipparion* sp., Ayusbamba. ×0·80.
FIG. 6. Pm_2, *Parahipparion* sp., Ayusbamba. ×0·80.
FIG. 7. M^1, *Parahipparion* sp., Ayusbamba. ×0·80.

as compared with the condition at four or five years of age, but the antero-posterior diameter, or length, of the crown would be considerably reduced. The width of the crown has probably been a little reduced also, but judging from the very slight convergence of the labial and lingual sides of the prism, this transverse reduction is very small, probably not exceeding 1^{mm}. Making due allowance for advanced stage of wear and for individual variation, it is conceivable that the enamel pattern of this tooth might have been derived from the pattern exhibited by the first upper molar of any one of the species of *Parahipparion* in which the true molars have been observed. These teeth have not been observed in *P. peruanum*, the species that from its occurrence at Tirapata would seem most

likely to be found in Pleistocene formations at Ayusbamba. On the whole it appears that very little progress toward the specific identification of the upper molar of text-figure 7 is to be made through the study of its enamel pattern alone. Much better results can be obtained by comparing its dimensions with those of the various species of *Parahipparion*. Accordingly the length and width of the upper true molars of *P. saldiasi*, *P. bolivianum*, and *P. devillei* and the same dimensions of the upper milk molars of *P. peruanum* are quoted from Sefve and arranged in the following table.

Dimensions of Molars of *Parahipparion* in millimeters.

	M^1		M^2		M^3	
	Length.	Width.	Length.	Width.	Length.	Width.
Parahipparion burmeisteri	29·5	30·	29·	29·5	27·	24·
P. saldiasi	29·	29·	26·	26·	32·5	22·
P. bolivianum	25·	27·	--	--	--	--
P. devillei	27·	25·	--	--	--	--
P. devillei	24·	25·	23·	23·	24·	21·
	D^1		D^2		D^3	
P. peruanum	35·7	23·	28·	22·5	29·2	22·

The width of the crown of the upper molar from Ayusbamba, viz., 22^{mm}, is less than that recorded, in the table, for m^1 of any species of *Parahipparion*. *P. devillei* comes nearest, with a width of 25^{mm} for m^1, while *P. saldiasi* and *P. bolivianum* are much farther removed. A direct comparison with the first molar of *P. peruanum* is impossible, the permanent upper molars of that species being unknown; but as far as any inference can be drawn from the transverse dimensions of the deciduous teeth, I should expect to find the width of m^1 of *P. peruanum* about equal to that of *P. saldiasi*. Whether this inference is correct or not, the isolated upper molar from Ayusbamba is evidently from some small-sized species of *Parahipparion*.

The posterior portion of the skull of *Parahipparion* has never been described, although five species of the genus have been recognized. The only cranial parts, besides the teeth, that have previously been collected, are the maxillary, premaxillary and palatine elements, and the mandible. Therefore the Yale Expedition was fortunate in securing at Ayusbamba a skull apparently belonging to this genus. This specimen, though far from complete, is composed largely of parts regarding which we have had no definite knowledge. A careful

search was made along the bottom and sides of a small ravine where this specimen occurred, but the rest of the skull was not found.

There was, in the possession of Dr. Romualdo Aguilar of Cuzco, a fragment of a small equine skull with several teeth, that came from very near this same place. Although I have had no opportunity to examine this specimen closely, its general appearance and the circumstances under which it was collected lead me to believe that it may be from the same skull as the portion taken later by the Yale Expedition. I trust that Dr. Aguilar will soon publish views and a description of his specimen.

The posterior part of the skull is shown in Plate VI, figure 1, together with two disconnected but important pieces of the nasal and premaxillary bones that are placed, as nearly as possible, in their true relative positions. Compared with the view of the skull of *Onohippidium compressidens* (fig. 2), it is at once seen that the skull from Ayusbamba was characterized by slender, freely projecting nasal bones, very similar to those of *Onohippidium* and *Hippidium bonaerense*. A conspicuous cheek-groove, beneath the elongated ascending process of the premaxilla, corresponds in part to the anterior chamber of the "fossa lacrymalis" of *Onohippidium*. It is the latter genus that this skull approaches most nearly in the form of the nasal bones, in the cheek-grooves of the maxillae, and in the depth of the alveolar portions of the maxillæ below the facial crests. In the shape of the zygomata and in the narrower preorbital breadth of the skull, as seen in Plate VII, figure 1, the resemblance is rather with *Hippidium bonaerense*. The posterior view of the skull is shown in Plate VI, figure 3, and its palatal or lower surface in Plate VII, figure 2. The skull, while indicated by the sutures to be that of a full-grown animal, is smaller in nearly every dimension than that of *Hippidium bonaerense*, especially in the transverse measurements. The contrast in size with the skull of *Onohippidium* is even greater. To compare the skull from Ayusbamba with those of *Onohippidium compressidens* and *Hippidium bonaerense* as fully as possible, I have made use of valuable data recorded by Sefve, and have arranged some of the principal measurements of these three crania in the accompanying table.

Although the skull from Ayusbamba and that of *Onohippidium compressidens* differ greatly in actual size, their proportions are so nearly alike that their generic separation by cranial characters alone, irrespective of size, would be difficult and unsatisfactory. In referring the Ayusbamba skull provisionally to *Parahipparion* I am influenced not only by the slight differences in cranial form, but also by what is known of the geographic distribution of the genera *Parahipparion* and *Onohippidium*.

Dimensions of skulls in millimeters.	Onohippidium compressidens.	Hippidium bonaerense.	Parahipparion sp. from Ayusbamba.
Length, total	588	580	--
From posterior margin of foramen magnum to anterior border of p^2	430	410	--
From posterior margin of foramen magnum to posterior border of m^3	244	231	228*
From posterior margin of foramen magnum to anterior border of orbit	241	230	222
From occipital point to anterior border of orbit	268	248·5	248
Maximum zygomatic breadth	220	213	200
Zygomatic breadth across glenoid surfaces	216	207	191
Occipital condyles, maximum height	46	40	39
Occipital condyles, maximum breadth	33	26	25
Breadth across outer margins of condyles	102·5	90	84
Breadth of os occipitale	129†	115	110
Breadth of os occipitale + os petrosum	141	134	125
Height of occipital region	126	108	110
Maximum height of foramen magnum	47·5	34	37
Maximum breadth of foramen magnum	45	45	32

The fossil horses that have been found in the mountains of Peru and Bolivia apparently belong to small short-legged species of *Parahipparion*, while *Onohippidium compressidens*, an animal with larger head and longer limbs, has been found only in the pampas formation of the Province of Buenos Ayres, near the Atlantic coast.

* Taken to the alveolus.

† Sefve gives 219^{mm}. According to the context this should read 129^{mm}.

Art. X.—*The "Dam" at Cheshire, Connecticut;* by Freeman Ward.

In the readjustment of the pre-Glacial Farmington River dams of glacial drift are considered to play an important part.* One of these dams—at Cheshire—is thought to have ponded the waters to the north till an outlet was formed to the Quinnipiac River by the cutting of the gorge near South Meriden. The writer believes that there is no dam of glacial drift at

Fig. 1.

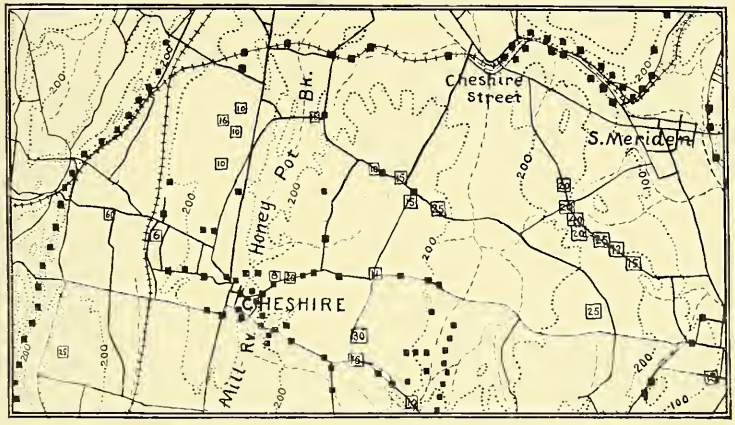


Fig. 1. Dotted lines are contours—100 foot interval. Dashed lines are streams. Full lines are roads. Black squares indicate that bed-rock is either at, or within five feet of, the surface. Figures in open squares show depth to bed-rock. Scale—length (E. & W.) of area shown is six miles.

Cheshire and that the change in the river's course was brought about in another manner.

A detailed study of the vicinity of Cheshire shows that there is no great accumulation of drift at that point. There is no more till or no more evidence of damming at Cheshire than at any other place in this region. In fact at the actual site of the supposed dam (at the heads of Mill River and Honey Pot Brook in the village of Cheshire) the bed rock is either directly exposed at the surface or is but a few feet below, as shown in fig. 1.

* Rice-Gregory, Manual of the Geol. of Conn., p. 252; Conn. Geol. and Hist. Surv., Bull. 6, 1906.

An examination of road cuts, wells, etc., along a strip a couple of miles wide from Yalesville to West Rock Ridge reveals the fact that if all the drift were entirely stripped from the rock surface the Quinnipiac River would still flow out through the gorge at South Meriden. A very natural path for the old Farmington to have taken is west of Cheshire along the course of the railroad: this is now filled with stratified drift. But even here a well shows the bed-rock surface to be at a height of 120 feet above sea level, while the head of the Quinnipiac gorge, at Cheshire Street, is 100 feet.

The walls of the gorge are largely covered with *till;* obviously the gorge was cut before the glacier arrived on the scene.

Since the drift seems to play no part in diverging the waters the most natural explanation lies in the bed-rock itself. It is believed that an anticlinal warping of the bed-rock on an axis running about N. 70° W. would accomplish the result. A gentle anticline having that same general axis is known some miles to the southeast between the ends of Saltonstall Ridge (Pond Rock) and Totoket Mountain. Again, the main trend of the gorge itself is N. 70° W. and it is possible that the cutting was initiated at that particular place because of some fracturing along a line parallel to the anticlinal axis. It is possible, too, that the southern termination of the Hanging Hills might be dependent on faulting belonging to this same period of movement.

The warping in question is pre-Glacial in time.

ART. XI.—*On a Progressive Development of Mechanics based upon a New Form of the Fundamental Principle of the Science;* by H. M. DADOURIAN.

THERE are two general types of methods which are used in developing systems of Mechanics, and which may be called the differential and the integral types. Newton's method based upon his laws of motion is of the first type, while methods based upon the principle of least action, or upon some equivalent integral principle, are of the second type. In order to differentiate between systems of Mechanics which are based upon differential principles and those based upon integral principles we will call the former Newtonian systems and the latter Lagrangian systems.

In view of the fact that both of these systems are the result of attempts to make a sketch of the same physical universe it is natural to ask: Is the difference between the two systems due to a difference in point of view or is it more intrinsic? Did Newton and Lagrange simply sketch the same dynamical structure from different angles, or did they picture two distinct and different objects? That these masters portrayed the same physical universe there is no doubt; yet it will not be correct to state that the pictures which they drew differ only in perspective. There is a difference between the two systems which is more fundamental than the terms "point of view" and "angle of observation" imply. The relation of Newton's system of Mechanics to that of Lagrange may be illustrated by a comparison between an "unassembled" picture of a machine with its "assembled" picture. In an unassembled picture of a generator, for instance, the pictures of individual mechanisms, such as the frame, the armature, the field coils, etc., are shown and are so placed as to give you a clear idea as to their relative positions in the assembled machine. On the other hand, only a few of the mechanisms are visible in the assembled picture, the rest being concealed by the frame. Newton's system represents an unassembled picture of physical phenomena. It aims at bringing into view the inner mechanisms of the interactions which result in natural phenomena. Unfortunately it is not always possible to reach this goal. We are very often unable to apply Newton's system of Mechanics to our problems. In other words, it is not always possible to take the machine to pieces. In such a case an assembled picture is drawn by the Lagrangian method. This, however, is not as satisfactory as an unassembled picture, because in the former the nature of the inner mechanisms is left to the imagination to unravel. Our knowledge of a physical phe-

nomenon is not satisfactory until we can apply it to the Newtonian system of Mechanics. In fact we may state that the extent to which the Newtonian system can be applied to a group of phenomena is a measure of the clearness with which we understand them.

It is therefore of the utmost importance for the development of physical science to have the principles which underlie the Newtonian Mechanics as clearly stated as possible. The fact that so many eminent scientists have severely criticized Newton's laws of motion indicates that these laws are not the best possible foundation upon which Newtonian Mechanics can be based. Some of the important points raised by the critics of Newton's laws are contained in the following extract from Hertz:*

"We swing in a circle a stone tied to a string, and in so doing we are conscious of exerting a force upon the stone. This force constantly deflects the stone from its straight path. If we vary the force, the mass of the stone, and the length of the string, we find that the actual motion of the stone is always in accordance with Newton's second law. But now the third law requires an opposing force to the force exerted by the hand upon the stone. With regard to this opposing force the usual explanation is that the stone reacts upon the hand in consequence of centrifugal force, and that this centrifugal force is in fact exactly equal and opposite to that which we exert. Now is this mode of expression permissible? Is what we call centrifugal force anything else than the inertia of the stone? Can we, without destroying the clearness of our conceptions, take the effect of inertia twice into account,—first as mass, secondly as force? In our laws of motion, force was a cause of motion, and was present *before* the motion. Can we, without confusing our ideas, suddenly begin to speak of forces which arise through motion, which are a consequence of motion? . . . These questions must clearly be answered in the negative. The only possible explanation is that, properly speaking, centrifugal force is not a force at all. . . . But, what now becomes of the demands of the third law, which requires a force exerted by the inert stone upon the hand, and which can only be satisfied by an actual force, not a mere name?"

"I do not regard these as artificial difficulties wantonly raised: they are objections which press for an answer. Is not their origin to be traced back to the fundamental laws? The force spoken of in the definition and in the first two laws acts upon a body in one definite direction. The sense of the third law is that forces always connect two bodies, and are directed from the first to the second as well as from the second to the first. It seems to me that the conception of force assumed and created in us by the third law on the one hand, and the first two laws on the other hand, are slightly different. This slight difference may be

* Heinrich Hertz, Principles of Mechanics, p. 5.

enough to produce the logical obscurity of which the consequences are manifest in the above example."

These remarks of Hertz apply just as well to a particle which is given a longitudinal acceleration as they do to one which has a transverse acceleration: to a body which has an angular acceleration as to one which has a linear acceleration.*

It must be stated that the critics of Newton's laws have had greater success in their diagnoses than in their remedies. While most of the criticisms have been well taken, the proposed substitutes for the laws of motion have been unsatisfactory. Hertz proposed to replace Newton's Mechanics by another system based upon the principle of *straightest path.* Therefore to accept Hertz's proposal amounts to discarding Newton's system and not to improving it. Some enthusiasts of the principle of the conservation of energy have advocated to base dynamics on this principle alone without realizing that it is not sufficient and that the principles of the conservation of linear momentum and of angular momentum are necessary to form an adequate basis. Besides, a system of Mechanics based upon these principles can serve the purpose of Newton's Mechanics no more than Lagrange's system. Systems based upon integral principles can supplement but not supplant Newton's Mechanics.

Ernst Mach and Karl Pearson have each proposed† a set of postulates to take the place of the laws of motion in which the mutual accelerations of particles are made the central concepts. Without going into a detailed discussion of these postulates it may be stated that they contain too many difficult concepts and are too complex to be understood by the beginner, consequently they are not suitable bases for Newtonian Mechanics.

While the systems of Lagrange and Hertz can not fill the place of Newton's system they indicate the direction in which the latter can be improved. These systems are developed in a manner which may be called the *unitary form of development.* The entire structure of each system is based upon a single principle from which are derived all special laws and relations. This underlying principle permeates the entire subject and gives direction to its development. It makes the science a closely connected and logically developed unit.

* It is strange that many authors of Mechanics have felt a necessity for "explaining centrifugal force," while no such feeling is shown with regard to the analogous vector magnitude in motion of translation, which is called linear kinetic reaction, in this paper. This is another indication that the famous laws of motion have something vague about them even to the experts on the subject. This is due to the lack of an adequate definition of the term "action" used in the third law.

† Ernst Mach, Science of Mechanics, p. 243. Karl Pearson, Grammar of Science, Chapter VIII.

In this connection it will not be amiss to digress a little on the meanings of the terms "principle" and "law." These terms are often used interchangeably in scientific terminology. There is, however, a wholesome tendency to limit their use to convey two distinct and different ideas. A principle is a generalization derived from a great number of facts. A law, on the other hand, is of the nature of a definition. The former often has to do with an invariant of nature, while the latter gives the form of dependence of one variable upon others. A principle is universally true and of general applicability; the validity of a law is conditional and its domain of applicability limited. Principles are intuitive, they appeal to inherited instincts and acquired experience. Laws are empirical, they appeal to the intellect and personal knowledge. On this view the conservation of energy, the conservation of momentum and Newton's third law of motion are principles, while the second law of motion and the law of gravitational attraction are laws.

The greatest field for improvement in the Newtonian system of Mechanics lies in the statement of its underlying principle and in the construction of the system upon this principle as foundation. In Newton's laws of motion a real principle (the third law), a definition (the second law), and a special law (the first) are placed at parity, to say nothing of the points brought forward in the criticisms made by Hertz, Mach, and others. On the other hand, the various sets of postulates which have been proposed as substitutes for Newton's laws have their own limitations. These postulates do not have the simplicity and directness of the laws of motion. Besides, they contain principles which are not characteristic of Dynamics. For instance, the law of the parallelogram of forces, which is often represented as a dynamical principle, is a purely geometrical axiom in its general form. When applied to forces it only states that forces are vector magnitudes and consequently obey the geometrical principle of the independence of mutually perpendicular directions.

When all special laws, definitions, and non-dynamical axioms are brushed aside there remains a single dynamical principle, of which the principles of virtual work, of least action, of least curvature, and of least constraint are different forms. The form in which the principle is stated determines, in a great measure, the character of the system of Mechanics which is based upon it. Therefore, when the system of Mechanics is given, as in the present case, the principle must be so stated as to satisfy its needs. The Newtonian system of Mechanics is primarily the beginner's Mechanics; therefore the statement of the principle should be adapted to the needs of the beginner as well as those of the advanced student. Like the second law

of Thermodynamics it should be simple and direct, yet capable of broad interpretation. It should convey to the student a depth of meaning and a breadth of applicability commensurate with his knowledge and ability.

In a recent book the present author has based the subject upon a single principle and developed it in a manner which, he believes, deserves the attention of all interested in the science of Mechanics. The principle which is made the foundation of the subject states:

The sum of all the external actions to which a body (system) or a part of a body (system) is subject at any instant vanishes.

$$\Sigma \mathbf{A} = 0^* \qquad \text{(A)}$$

The significance of this principle, which may be called the *action principle*,† is gradually broadened as the needs of the student require it. This is done at four different stages and in connection with four different classes of problems, namely, the equilibrium and motion of a particle and of a rigid body. The following statement gives the salient points in the development and the line of reasoning used.

(1) *Equilibrium of a particle.* A particle which is in equilibrium is subject to only one type of action, namely, the actions of other particles which tend to set it in motion. The vector magnitude which represents the *action of one particle upon another* is called a *force*; consequently all actions which come into play in this particular class of problems are forces. Therefore the action principle states that the sum of all the forces to which a particle in the state of equilibrium is subject at any instant vanishes. Hence the following relations form the conditions of equilibrium of a particle:

$$\Sigma \mathbf{F} = 0\,, \quad \begin{matrix} \Sigma X = 0\,, \\ \Sigma Y = 0\,, \\ \Sigma Z = 0\,, \end{matrix} \qquad \text{(I)}$$

where $\mathbf{F}$ denotes a force, while X, Y, and Z denote the magnitudes of its components.

(2) *Equilibrium of a rigid body.* It is shown that a rigid body is capable of having two distinct and independent types of motion, namely, a motion of translation and a motion of rotation. Consequently, a rigid body is capable of being subjected to two distinct types of action, one of which relates to translation, while the other is connected with rotation. These

* Letters in black type denote vector magnitudes.

† In the Newtonian system of Mechanics the term *action* is used in a sense different from that in advanced Dynamics, therefore there is no danger of confounding this principle with the principle of least action.

are called *linear action* and *angular action*, respectively. Therefore, the action principle states:

$$\Sigma(\mathbf{A}_l + \mathbf{A}_a) = 0\,, \qquad (A')$$

where $\mathbf{A}_l$ denotes a linear action and $\mathbf{A}_a$ an angular action. But since $\mathbf{A}_l$ and $\mathbf{A}_a$ are independent of each other, the principle may be stated in two parts:

I. *The sum of all the external linear actions to which a body or a part of a body is subject at any instant vanishes:*

$$\Sigma\mathbf{A}_l = 0\,. \qquad (A_l)$$

II. *The sum of all the external angular actions to which a body or a part of a body is subject at any instant vanishes:*

$$\Sigma\mathbf{A}_a = 0. \qquad (A_a)$$

In case of equilibrium, forces are the only type of linear action which come into play; on the other hand, torques (defined as that *action of one body upon another which tends to produce a motion of rotation*) are the only type of angular action. Therefore, the following well-known conditions of equilibrium follow, immediately, from the two sections of the action principle:

$$\Sigma\mathbf{F} = 0\,, \quad \begin{matrix} \Sigma X = 0\,, \\ \Sigma Y = 0\,, \\ \Sigma Z = 0. \end{matrix} \qquad (I)$$

$$\Sigma\mathbf{G} = 0\,, \quad \begin{matrix} \Sigma G_x = 0\,, \\ \Sigma G_y = 0\,, \\ \Sigma G_z = 0\,, \end{matrix} \qquad (II)$$

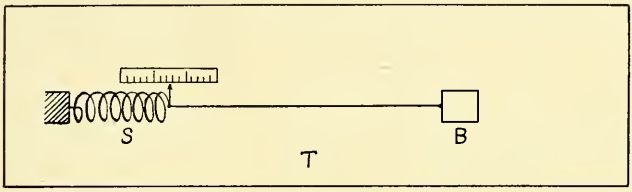
where $\mathbf{G}$ denotes a torque, while G_x, G_y, and G_z denote the magnitudes of its components.

(3) *Motion of translation.* Here the concept of *linear kinetic reaction* is introduced as a linear action which is the counterpart of force and which appears whenever a body is given a linear acceleration. The quantitative definition, or the measure, of this new form of action is illustrated by means of the two following ideal experiments.

(a) An apparatus consisting of a spring balance S (fig. 1), an extensible string of great length, and a block B is set up on a perfectly smooth horizontal table T. The string connects the block with one end of the spring balance, the other end of which is fixed on the table. Suppose, now, two persons to perform the following experiment. One of the experimenters

pulls the block away from the balance, thereby stretching the string; while the other observes the readings of the balance. Since the system is in equilibrium, two equal and opposite forces must act at the two ends of the string. In other words, the pull exerted by the block upon the string equals that registered by the balance. The pull exerted by the block is obviously due to the pull exerted by the person who holds it. When the block is released it is observed that the reading of

FIG. 1.



the balance does not drop to zero at once. In fact the balance registers a pull so long as the length of the string is greater than its natural length. In other words, the block exerts a pull upon the string in spite of the fact that there is no force which tends to pull it to the right, nor a force, like friction, which resists its motion towards the left.

In order to account for this action of the block we may take one of the following two points of view. We may attribute it to the block itself, and using the common mode of expression state, "the block resists the accelerating force of the string and thereby acts upon the latter because it has *inertia*." Evidently this amounts to stating, "the block offers a resistance because it has the property of resisting." In this "explanation" the term *inertia* acts as a sop to the mind. We can, on the other hand, take the position that the block is just as helpless against acceleration as a person falling in space is against falling: that bodies have the property of interaction but not one of resistance to action. If we adopt this point of view we must suppose that the inertia of the block and its action upon the string is the result of an interaction between the block and the ether (or whatever may take its place in future physical theories). In other words, we must suppose that the ether acts upon a body whenever the latter is given an acceleration.* This new type of action, which we will call *linear kinetic reac-*

* Some physicists may consider it a mistake to bring the ether into Dynamics. These men should remember that the ether has already entered this field, and that our acceptance of the electromagnetic origin of mass is a very important concession to the claims of the ether for a place in the Science of Dynamics.

tion, differs from forces and torques, which represent interactions between matter and matter and not between ether and matter.

In order to obtain a quantitative definition of the kinetic reaction, suppose the experiment to be continued in the following manner. After the block is released one of the experimenters observes the readings of the balance, while the other records the position of the block at different instants. Then a comparison of the readings of the balance with the corresponding accelerations of the block (obtained from the observations of the second experimenter) gives the following result:

$$\frac{R'}{f'} = \frac{R''}{f''} = \frac{R'''}{f'''} = \ldots . m , \qquad (1)$$

where $f^{(i)}$ denotes the acceleration of the block at the instant when the balance registered the pull $R^{(i)}$, while m is a constant which is called the *mass* of the block. Thus the kinetic reaction of a body is proportional to its acceleration.

If the blocks be replaced by other blocks and the experiment repeated the same result will be obtained, with the exception that the constant m will, in general, be different for different blocks. If the readings of the balance are compared when different blocks have equal accelerations it will be found that

$$\frac{R_1}{m_1} = \frac{R_2}{m_2} = \frac{R_3}{m_3} = \ldots . f , \qquad (2)$$

where m_1, m_2, etc., denote the masses of the blocks, determined in the foregoing manner, while f denotes the common acceleration. Therefore, the kinetic reaction of different bodies having equal accelerations are proportional to their masses.

It follows from (1) and (2) that the measure of the linear kinetic reaction is given by the relation

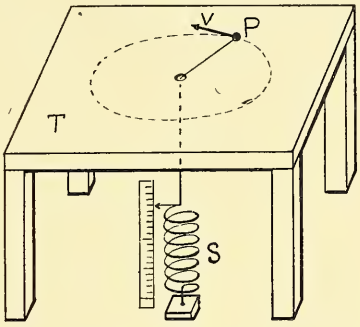
$$\mathbf{R}_\tau = - m_\tau \mathbf{f}_\tau , \qquad (3)$$

where the subscripts are introduced to emphasize the fact that all three of the magnitudes involved in (3) relate to a motion in which the acceleration is tangential, or, longitudinal, while the negative sign is introduced to take into account the fact that $\mathbf{R}_\tau$ and $\mathbf{f}_\tau$ are oppositely directed.

(b) In the preceding experiment the acceleration was longitudinal: we will now consider a case in which it is transverse. Let P (fig. 2) be a particle placed upon a perfectly smooth horizontal table T, and connected to a spring balance S by means of an inextensible string, which passes through a smooth hole in the center of the table. If the particle be set in motion

so that it will describe a circular path it will be observed that its speed remains constant and that the spring balance registers a pull. It follows from the second observation that the particle exerts a force upon the string and in turn is pulled by the string. Considering the particle alone, we see that it is pulled towards the hole but does not approach it, and this in spite of the fact that no force is acting upon the particle to counterbalance that exerted by the string. In order to account for this fact we must introduce, again, the concept of the kinetic reaction.

Fig. 2.



The measure of this reaction may be obtained in a manner similar to that employed in (*a*). When different transverse accelerations are given to the particle by changing its speed, the radius of its path, or both: and then these accelerations are compared with the corresponding readings of the spring balance, the following relations will be found:

$$\frac{R'}{f'}=\frac{R''}{f''}=\frac{R'''}{f'''}=\ldots\ldots=m \qquad (4)$$

where $R^{(i)}$ is the reading of the balance which corresponds to the acceleration $f^{(i)}$, while m is a constant which may be called *transverse mass.* Therefore the transverse kinetic reaction of a particle is proportional to its transverse acceleration.

If, on the other hand, the particle is replaced by others and the experiment repeated, the following relations are obtained:

$$\frac{R_1}{m_1}=\frac{R_2}{m_2}=\frac{R_3}{m_3}=\ldots\ldots=f, \qquad (5)$$

where m_1, m_2, etc., denote the transverse masses of the particles, while R_1, R_2, etc., denote the readings of the spring balance

which corresponds to a common transverse acceleration f. Thus the transverse kinetic reactions of different particles having equal transverse accelerations are proportional to their transverse masses.

It follows, therefore, that the quantitative definition of the transverse kinetic reaction is given by the relation

$$\mathbf{R}_n = -m_n \mathbf{f}_n , \tag{6}$$

where the subscripts are introduced in order to emphasize the fact that the magnitudes involved in (6) relate to the normal, or transverse, direction.

When the same system of units are used to measure R_τ, R_n, f and f_n, it will be found that m_τ and m_n are equal. Therefore, when a particle has a transverse as well as a longitudinal acceleration, the total linear kinetic reaction is the sum of $\mathbf{R}$ and $\mathbf{R}^n$. Thus,

$$\begin{aligned} \mathbf{R}_l &= \mathbf{R}_\tau + \mathbf{R}_n \\ &= -m(\mathbf{f}_\tau + \mathbf{f}_n) \\ &= -m\left(\dot{\mathbf{v}}_\tau - \frac{v^2}{\rho}\right) \\ &= -m\dot{\mathbf{v}} , \end{aligned} \tag{7}$$

where $\mathbf{v}$ denotes velocity, $\dot{\mathbf{v}}_\tau$ the tangential component of the acceleration, and $\dot{\mathbf{v}}$ the total acceleration of the particle; while ρ denotes the radius of curvature of the path, measured from the center of curvature.

The linear kinetic reaction and forces are the only types of linear action which a body experiences. Therefore, the first section of the action principle leads to the relations:

$$\Sigma \mathbf{F}_i + \mathbf{R}_l = 0 ,$$

or

$$\begin{aligned} \mathbf{F} &= -\mathbf{R}_l \\ &= m\dot{\mathbf{v}} , \end{aligned} \tag{III}$$

where $\mathbf{F}$ denotes the resultant force.

The last relation, which is called *force equation*, is then resolved into two component equations which correspond to the directions parallel to the tangent and to the normal to the path of the particle. Thus

$$\mathrm{F}_\tau = m\dot{v}$$

$$\mathrm{F}_n = -m\frac{v^2}{\rho}$$

and

$$\mathrm{F} = m\sqrt{\dot{v}^2 + \frac{v^4}{\rho^2}} ,$$

where F, F_τ, and F_n denote, respectively, the magnitudes of the resultant force and of its tangential and normal components.

(4) *Motion of rotation.* Here the concept of *angular kinetic reaction* is introduced as the counterpart of torques, which come into play whenever a body is given an angular acceleration. The quantitative definition of this new type of action is obtained in a way quite analogous to the manner in which the measure of the linear kinetic reaction was obtained.

Consider a flywheel, which is perfectly balanced and perfectly free to rotate about a horizontal axis. In order to start the flywheel in motion or to stop it a torque must be applied. Therefore the flywheel experiences an angular kinetic reaction when it is given an angular acceleration. If the angular acceleration of the flywheel is observed at different instants and simultaneous observations are made of an arrangement which measures the kinetic reaction it will be found that the following relations hold:

$$\frac{R_a'}{\dot{\omega}'} = \frac{R_a''}{\dot{\omega}''} = \frac{R_a'''}{\dot{\omega}'''} = \ldots = I, \tag{8}$$

where $\dot{\omega}$ denotes the angular acceleration, R_a the corresponding kinetic reaction, and I a constant which is called *moment of inertia* or *angular inertia* and which plays a role analogous to that played by the mass of a body in motion of translation. Thus the angular kinetic reaction of a body rotating about a given axis is proportional to the angular acceleration.

If, on the other hand, equal angular accelerations are given to different bodies or to the same body about different axes and the moments of inertia determined in the foregoing manner the following relations will be found:

$$\frac{R_a'}{I'} = \frac{R_a''}{I''} = \frac{R_a''}{I'''} = \ldots \dot{\omega}, \tag{9}$$

where $\dot{\omega}$ denotes the common angular acceleration. Therefore, the angular kinetic reactions of different bodies, or of the same body relative to different axes, are proportional to the corresponding moments of inertia. It follows therefore that the following relation defines the angular kinetic reaction:

$$\mathbf{R}_a = -I\dot{\omega}, \tag{10}$$

where the negative sign is introduced to take into account the fact that $\mathbf{R}_a$ and $\dot{\omega}$ are oppositely directed.

The angular kinetic reaction and torques are the only types of angular actions which come into play; therefore the second section of the action principle states:

$$\Sigma \mathbf{G}_i + \mathbf{R}_a = 0 ,$$

or

$$\mathbf{G} = -\mathbf{R}_a$$

$$= I\dot{\omega} , \qquad \text{(IV)}$$

where $\mathbf{G}$ denotes the resultant torque. By comparing the expression for the moments of the kinetic reactions of the elements of a rotating body with equation (IV) it may be shown that the foregoing experimental definition of moment of inertia is equivalent to the common analytical definition.

In this treatment of the science of mechanics the principles of the conservation of dynamical energy, of linear momentum and of angular momentum are derived from the action principle and are used as supplementary principles.

The form of the statement of the action principle and the way in which its significance is developed do away with the difficulties which arise from confounding the linear kinetic reaction with a force and the angular kinetic reaction with a torque. A clear-cut distinction is made between force and torque on the one hand and the two forms of kinetic reaction on the other. *The former represent interactions between matter and matter while the latter represent interactions between ether and matter.* On this view inertia is not a resistance which bodies offer to an accelerating force. The conception of two gravitating particles attracting each other and at the same time resisting attraction, imparting acceleration yet offering resistance to acceleration, is obtained by analogy from tug-of-war. But the analogy does not hold good unless something is introduced into the conception of the gravitating particles which will play the same roll as the common ground on which the men playing tug-of-war stand. Without such a common ground there can be no tug-of-war. We can not "without destroying the clearness of our conceptions take the effect in inertia twice into account—first as mass and secondly as force." The point of view outlined here completes the analogy by introducing the necessary "common ground."

In addition to clarifying the fundamental principle, the development outlined in this paper unifies the presentation of the science of Mechanics to a great extent, makes it progressive and graded. A tremendous gain is thus made in economy of effort.

The following derivation of Newton's third law of motion illustrates the simplicity with which dynamical laws and theorems can be derived from the action principle.

Consider two interacting particles: Let m_1 and m_2 be the masses, and $\dot{\mathbf{v}}_1$ and $\dot{\mathbf{v}}_2$ the accelerations of the particles. Fur-

ther let $\mathbf{F}_{12}$ denote the force on m_1 due to m_2 and $\mathbf{F}_{21}$ the force on m_2 due to m_1. Then if the two particles are considered as one system the only external actions are their kinetic reactions, therefore the action principle gives

$$m_1\dot{\mathbf{v}}_1 + m_2\dot{\mathbf{v}}_2 = 0, \tag{1}$$

or

$$\frac{\dot{\mathbf{v}}_1}{\dot{\mathbf{v}}_2} = -\frac{m_2}{m_1}, \tag{2}$$

which states that the mutual acceleration of two particles are oppositely directed and are inversely proportional to their masses. When the particles are regarded as separate systems, then the action principle gives

$$\mathbf{F}_{12} + m_1\dot{\mathbf{v}}_2 = 0 \tag{3}$$

and

$$\mathbf{F}_{21} + m_2\dot{\mathbf{v}}_2 = 0. \tag{4}$$

From the last two equations and equation (1) we obtain

$$\mathbf{F}_{12} = -\mathbf{F}_{21}, \tag{5}$$

which is Newton's third law of motion.

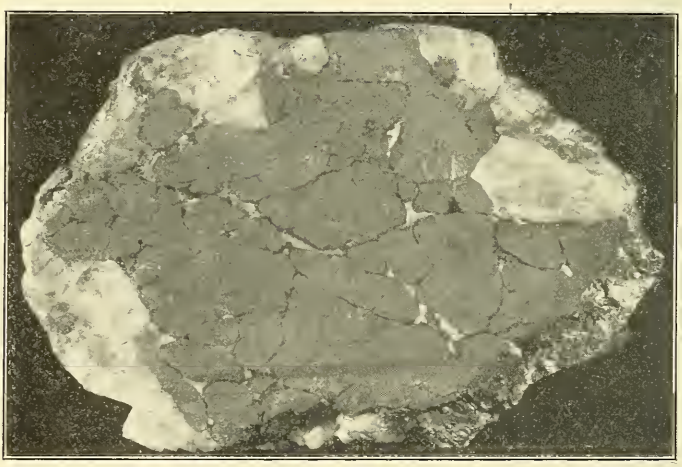
Sloane Physical Laboratory,
Yale University, New Haven, Conn.

Art. XII.—*Temiskamite, a new nickel arsenide from Ontario;* by T. L. Walker.

A few weeks ago the Royal Ontario Museum of Mineralogy received some specimens of niccolite from the Moose Horn Mine, Elk Lake, Ontario. On examining some of the material it was observed that much of the supposed niccolite was much paler in color than normal niccolite. The examinations thus initiated are detailed in the following paragraphs.

Paragenesis.—This mineral occurs in calcite veins carrying niccolite and smaller amounts of native bismuth and silver.

Fig. 1.



The new mineral appears to be one of the first to form. It is bordered and fringed by niccolite and bismuth, while the calcite appears to be later, as it fills in all the space between the branching masses of the other minerals.

Physical properties.—Color, silver-white with a touch of red, tarnishing very quickly to madder gray, and after prolonged exposure to tints resembling those of bornite. Hardness, 5·5; specific gravity, 7·901; fusibility, 2; luster, metallic; opaque; not magnetic; streak, brownish black.

Crystallography.—This mineral occurs in radiating fibrous masses suggesting rammelsbergite in structure. No crystallized material has yet been obtained. Traces of cleavage are seen upon examining polished surfaces with the microscope;

The radiating fibrous masses are built up into arborescent botryoidal forms, the outer surface sometimes covered with niccolite or bismuth or by a very thin layer of some undetermined black mineral resembling native arsenic (figure 1).

Chemical properties.—In strong nitric acid the mineral is attacked with violence accompanied by the evolution of red fumes and the separation of a very small amount of sulphur, which later oxidizes so that complete solution results. In sulphuric acid the decomposition is slower while in hydrochloric acid the mineral is only very slowly dissolved. Closed tube, a very slight deposit of crystallized arsenious oxide; open tube, abundant deposit of the same oxide, the oxidized residue greenish in color; plaster cast, coating for arsenic and in smaller degree bismuth; charcoal alone, the easily fusible mineral melts to a bright bead and oxidizes, covering the charcoal with arsenious acid, the bead after long treatment being magnetic.

Chemical analysis.—Several grams of this mineral apparently free from the associated minerals was selected, ground finely, dried at 110° C. and analyzed with the following result:

Nickel	49·07% ÷ 58·7 = ·8359	·8652	
Cobalt	1·73% ÷ 59· = ·0293		
Iron	trace		
Arsenic	46·34% ÷ 75· = ·6179	·6500	
Sulphur	1·03% ÷ 32· = ·0321		
Antimony	not determined		
Bismuth	·55%		
	98·72%		

·8652 ÷ 2163 = 4 ratio of Ni + Co,
·6500 ÷ 2163 = 3·005 ratio of As + S.

From the above analysis and calculation it seems very probable that this is a new mineral whose chemical composition may be expressed by the formula $(Ni,Co)_4.(As,S)_3$ or, apart from very small proportions of isomorphous elements, Ni_4As_3.

The small amount of bismuth, it will be observed, is not included in the above calculation, as it seems probable that it occurs in the form of small particles of native bismuth included in the mineral.

Although this mineral has not yet been found crystallized it seems reasonable to regard it as a new species, first, because of the exact ratio resulting from the analysis and calculation, and second, because we do not know any minerals which could be mixed so as to produce an aggregate of the above composition. Millerite contains as high a percentage of nickel but in it the

sulphur percentage is very high. In the classification this new mineral belongs to the dyscrasite group and to the basic division of the sulphides.*

The mine from which the material was obtained lies some distance to the west of Cobalt, but as the mineral associations are the same in both camps it seems probable that this new mineral should be found in the Cobalt mines if carefully looked for. To indicate the region from which the first specimens were obtained I suggest that this mineral be called Temiskamite from the district of Temiskaming in northern Ontario.

I wish to thank my assistant, Mr. H. V. Ellsworth, for assistance in connection with the chemical analyses.

Royal Ontario Museum of Mineralogy,
Toronto, Ontario, December, 1913.

* Since writing the above, my attention has been called to the new mineral Maucherite, recently described. This mineral has the chemical composition represented by Ni_3As_2 and is apparently closely related to Temiskamite.

ART. XIII.—*The Use of the Ammonium Salt of Nitrosophenylhydroxylamine ("Cupferron") in the Quantitative Separation of Titanium from Iron;* by WILLIAM M. THORNTON, JR.

[Contributions from the Kent Chemical Laboratory of Yale Univ.—cclix.]

NITROSOPHENYLHYDROXYLAMINE was first synthesized by Wohl.* The ammonium salt of nitrosophenylhydroxylamine was brought into service in analytical chemistry by Baudisch† for the estimation of either copper or iron, the separation of these two metals from various others, and indirectly for the separation of the former from the latter. Owing to these properties, the trivial name of "Cupferron" has been applied to the ammonium salt of nitrosophenylhydroxylamine. The analytical data given by Baudisch are few and not absolutely confirmatory. Since then, however, various other workers (notably Biltz and Hödtke,‡ Hanus and Soukup,§ and Fresenius‖) have thoroughly demonstrated the value of this reagent for the quantitative precipitation of either copper or iron and their separation from various other bodies. In connection with other work, Schroeder¶ has made the statement** that titanium and zirconium could be quantitatively precipitated from their acid solutions by the "cupferron" reagent, and that experiments were in progress for the estimation of these two elements. Schroeder, however, gave no experimental data and has not published further upon the subject. Bellucci and Grassi†† have shown that from solutions, moderately acidified with either sulphuric or hydrochloric acid, titanium could be quantitatively precipitated by the "cupferron" reagent, and that titanium could also, under these conditions, be quantitatively separated from aluminum. Under these circumstances the titanium comes down as a very bulky, readily filterable, precipitate of canary yellow color. In the opinion of the aforesaid authors the precipitate, after having been crystallized from ethyl alcohol, is the titanic salt of nitrosophenylhydroxylamine, corresponding to the formula $\left[\begin{matrix} C_6H_5-N=N-O \\ \| \\ O \end{matrix}\right]$ Ti.

* Ber. chem. Ges., xxvii, 1435, 1894.
† Chem. Zeitung, xxxiii, 1298, 1909.
‡ Zeitschr. anorg. Chem., lxvi, 426, 1910.
§ Ibid., lxviii, 52, 1910.
‖ Zeitschr. anal. Chem., l, 35, 1911.
¶ Zeitschr. anorg. Chem., lxxii, 89, 1911.
** Loc. cit., page 95.
†† Gazetta Chimica Italiana, Anno xliii, parte I, 570, 1913.

It has been known for a long time that certain organic acids, containing both hydroxyl and carboxyl groups, such as tartaric acid and citric acid, have the power to prevent the precipitation of certain metals when their solutions are made alkaline with sodium or potassium or ammonium hydroxide. This principle was made use of by Gooch* for the separation of titanium from iron; for, if the solution contain sufficient tartaric acid, the iron can be precipitated by ammonium sulphide as ferrous sulphide and the titanium will then be found entirely in the iron free filtrate. The next step is to oxidize the tartaric acid; for titanium is not precipitated in its presence by any of the reagents previously used for its gravimetric estimation. This was accomplished by Gooch,† after strongly acidifying with sulphuric acid by adding potassium permanganate to the boiling aqueous solution. This process is open to the objection that a great deal of manganese is thus introduced into the solution and is coprecipitated in some measure when the titanium is subsequently thrown down by hydrolysis of titanic acetate. A second precipitation is therefore necessary, which must be preceded by fusion with an appropriate flux and solution of the melt in acid. The author's experiments show that, after acidifying the filtrate from the ferrous sulphide, the titanium can be quantitatively precipitated by the "cupferron" reagent, notwithstanding the presence of tartaric acid.

Two solutions of titanic sulphate were employed for these experiments; which were prepared by warming potassium fluotitanate with concentrated sulphuric acid until all the hydrofluoric acid had been volatilized, pouring into cold water, and making up to known volume. The quantity of sulphuric acid used was such that the resulting solution contained about 10 per cent of absolute acid. In the case of the second solution, the trace of platinum was removed by saturating the solution with hydrogen sulphide, filtering off the platinic sulphide, boiling out the hydrogen sulphide, filtering again, and making up the solution to definite volume. The first solution was standardized by taking weighed portions of 25^{cm^3} and precipitating the titanium by hydrolysis of the acetate. The solution was made nearly neutral with redistilled ammonium hydroxide—until a faint permanent turbidity appeared. One cm^3 of a strong solution of ammonium hydrogen sulphite was added, followed by 15 grams of ammonium acetate and 20 grams of glacial acetic acid, and the solution made up to 400^{cm^3}. This solution was brought rapidly to boiling and maintained in ebullition for one minute. The precipitate was washed twenty times—first with boiling 5 per cent acetic acid, and finally

* Proc. Am. Acad. Arts and Sci., n. s., vol. xii, p. 435; Chem. News, lii, 55, 68.

† Loc. cit., p. 445.

with boiling water. In the usual manner the precipitate was ignited to titanic oxide and brought to constant weight over the Meker burner. Duplicate determinations gave the following results:

	Titanic sulphate soln.	Titanic oxide	
(a)	25^{cm^3} =◯= 37·308 grms.	0·1427 grm.	0·5226%
(b)	25^{cm^3} =◯= 27·319 grms.	0·1428 grm.	0·5227%

Since these two values agreed so closely, (b) was arbitrarily taken as correct. The second solution was standardized by taking two weighed portions of 25^{cm^3} and 24^{cm^3} respectively and determining the titanium in one (a) by the acetate method given above and in the other (b) by the "cupferron" method of Bellucci and Grassi* (the exact technique of which will be given presently). Duplicate determinations gave the following results:

	Titanic sulphate soln.	Titanic oxide	
(a)	25^{cm^3} =◯= 27·814 grms.	0·1066 grm.	0·3832%
(b)	24^{cm^3} =◯= 26·667 grms.	9·1022 grm.	0·3832%

Since these two determinations agreed exactly, the value here obtained was taken as correct.

A solution of ferric sulphate was prepared by dissolving Baker's analyzed ferric ammonium sulphate in water, adding 25^{cm^3} of concentrated sulphuric acid per liter to prevent the formation of basic salt, filtering, and making up to definite volume. In one portion (a) of 25^{cm^3} the iron was determined by titration with potassium permanganate after reduction by zinc —the potassium permanganate having been previously standardized against sodium oxalate.† In another portion (b) of 25^{cm^3} the iron was determined by precipitation with redistilled ammonium hydroxide in a platinum basin and ignition of the precipitate to ferric oxide. Parallel determination gave the following results:

	Ferric sulphate soln.	Ferric oxide
(a)	25^{cm^3}	0·2267 grm.
(b)	25^{cm^3}	0·2269 grm.

The value obtained in (a) by the volumetric method was arbitrarily taken as correct.

* Loc. cit.

† The sodium oxalate was obtained from the Bureau of Standards, Washington, D. C.

The supply of "cupferron" for these experiments was prepared in this laboratory according to the directions given by Baudisch.* An approximately 6 per cent solution of the salt was made by dissolving it in cold water and filtering from any insoluble residue that remained.

The first series of experiments was carried out with a view to ascertaining whether or not titanium could be completely precipitated and accurately determined in the presence of tartaric acid. To a solution containing a known quantity of titanium a little more than three times the weight of the titanic oxide present was added of tartaric acid. The solution was made neutral to litmus with ammonium hydroxide, then acid again with 5^{cm^3} of sulphuric acid (made by diluting acid of sp. g. = 1·84 with an equal volume of water), and the volume made up to 200^{cm^3}. A little more than the calculated amount of "cupferron" solution was added and the beaker set aside for the precipitate to settle. The supernatent liquid was tested by adding a few drops of the reagent, which were made to run down the wall of the beaker. The formation of a white precipitate of nitrosophenylhydroxylamine indicates that the reagent has been added in excess, while the formation of a yellow turbidity shows that the titanium had not been completely thrown out. It is well also to test the filtrate. The precipitate was filtered on paper using very gentle suction and washed twenty times with cold water. During the washing the suction should be almost stopped to prevent the wash water from running through too fast to accomplish much solvent work. The precipitate is very prone to develop mud cracks and should therefore be agitated with the stream of water from the wash bottle as much as possible. After having been sucked free from drainage water, the precipitate along with the filter was placed in a tared platinum crucible, dried at 110° C., very carefully heated until the volatile products of destructive distillation had escaped, the inclined open crucible ignited till all carbon had been consumed, and finally brought to constant weight over the Meker burner. If it is desired to save time, the precipitate can be dried by inclining the crucible, supporting the lid tongue downward on the triangle and edge of the crucible, and applying a small flame beneath the lid. The heat is thus deflected downward and the precipitate gradually dried from above with little danger of spattering.† It is unadvisable to dry the precipitate in the funnel; for at a low temperature the substance melts, or at least assumes a plastic condition, and penetrates the pores of the filter; moreover, the dried

* Chem. Zeitung, xxxv, 913, 1911.

† See Analytical Chemistry, Treadwell [translated by Hall], vol. ii, p. 29, 1910.

material is very brittle and on attempting to fold the paper and introduce it into the crucible particles are likely to fly away and be lost. In experiments (1) and (4) the filtration was carried out on asbestos in the perforated platinum crucible. Due to the above mentioned property, a little titanic oxide was found on the outer surface of the crucible after ignition. This method of filtration was therefore abandoned. Table I contains the results of three experiments.

Table I.

No.	TiO_2 taken grm.	TiO_2 found grm.	Error grm.	Tartaric acid grm.
1.	0·1428	0·1426	−0·0002	---
2.	0·1428	0·1429	+0·0001	0·5
3.	0·1066	0·1063	−0·0003	0·4

In the second series of experiments actual separation of titanium from iron was carried out. To facilitate the reduction of the iron the solution, to which tartaric acid equal to three times the weight of the titanic oxide and ferric oxide present had been added, was neutralized by ammonium hydroxide, 1 to 2^{cm^3} of sulphuric acid (1 : 1) added, and the volume made up to about 100^{cm^3}. Hydrogen sulphide was then introduced till the solution appeared colorless. If the iron is not thus reduced before its precipitation, titanium will be thrown down in part also.* The solution was then made ammoniacal and more hydrogen sulphide introduced, until the iron had been completely precipitated as ferrous sulphide—leaving the solution, however, alkaline to test-paper. The ferrous sulphide was filtered off and washed ten times with very dilute colorless ammonium sulphide. The filtrate was acidified with 25^{cm^3} of sulphuric acid (1 : 1), the hydrogen sulphide boiled out, the acid partially neutralized with ammonium hydroxide so as to leave about $2{\cdot}5^{cm^3}$ of sulphuric acid (1 : 1) for every 100^{cm^3} of the solution, and the "cupferron" added in the cold. Table II contains the results of four experiments.

Table II.

No.	TiO_2 taken grm.	Fe_2O_3 taken grm.	TiO_2 found grm.	Error grm.
4.	0·1428	0·2267	0·1424	−0·0004
5.	0·1428	0·2267	0·1430	+0·0002
6.	0·1066	0·2267	0·1068	+0·0002
7.	0·1063	0·2267	0·1061	−0·0002

* Cathrein, A., Zeitschr. Kryst., vi, 243, 1882; vii, 250, 1883.

In the third series of experiments the solution containing the titanium and iron was divided into two aliquot parts by weight. In one part the titanium was determined by the method already outlined. In the other part the iron was determined by the method of Gooch and Newton.* Table III contains the results of two experiments.

Table III.

No.	TiO_2 taken grm.	Fe_2O_3 taken grm.	TiO_2 found grm.	Fe_2O_3 found grm.	Error TiO_2 grm.	Error Fe_2O_3 grm.
8.	0·0716	0·1130	0·0719	0·1130	+0·0003	0·0000
9.	0·0717	0·1129	0·0716	0·1135	−1·0001	+0·0006

From the work of Bellucci and Grassi,† Fresenius,‡ and the author, it would seem that there should be no great difficulty attending the separation of titanium from iron, aluminum, and phosphoric acid, which are the substances with which titanium is commonly associated in nature. Experiments are now in progress by the writer for accomplishing this separation with the aid of the "cupferron" reagent, and the results will appears in a later issue of this journal.

6 January, 1914.

* This Journal, xxiii, 365, 1907. † Loc. cit. ‡ Loc. cit.

Art. XIV.—*A Contribution to the Optical Study of the Amphiboles;* by W. E. Ford.

The late Prof. S. L. Penfield was engaged at the time of his death upon an investigation of the chemical composition of the minerals of the Amphibole Group. A series of eleven analyses for this work had been made under his guidance, by Dr. F. C. Stanley, of amphiboles which ranged in composition from tremolite to hornblende. The specimens selected for analysis afforded unexcelled material for chemical investigation, and it is safe to say that few such series of authoritative analyses of the amphibole minerals can be found elsewhere. The article, as far as the discussion of the composition of the amphiboles was concerned, was practically complete at the time of Prof. Penfield's death and was subsequently published in this Journal.* It had been the intention of Prof. Penfield to supplement the discussion of the chemical composition of these amphiboles by a study of their optical properties. Unfortunately he was not able to do this, but it has seemed of considerable importance that this work should be done. In the majority of cases the identical specimens from which material for the analyses was taken were preserved in the Brush Mineral Collection. In the few cases where it was impossible to positively identify the specimen which had furnished the material, a specimen in the Collection and undoubtedly of the same suite, as the one analyzed, was used.

In studying the literature of the last twenty-five years it is surprising to find in how few cases both an analysis and an optical description of the same amphibole have been recorded. There are plenty of instances where one or the other is given, but unfortunately the two are seldom found combined in the same description. Therefore, if only as a matter of record, it seemed advisable to complete the investigation of these amphiboles by a determination of their optical characters. This work was started a number of years ago in the laboratory of Prof. Rosenbusch at Heidelberg, but through various causes it has only recently been possible to carry it to completion.

As far as possible the following optical facts were determined in each case: (1) the indices of refraction and the average index of refraction, (2) the angle of extinction on b (010) measured with the trace of the prismatic cleavage, and (3) the pleochroism. The value of the optical angle, 2V, was determined whenever possible by calculation, but no direct measurements of it were made. The indices of refraction were measured upon a total refractometer, at least two differently

* Vol. xxiii, p. 23, 1907.

orientated plates being used in each case. In a few instances, where the character of the material made the use of the total refractometer impossible, the mean index was determined under the microscope by the immersion of small fragments of the mineral in liquids having known indices of refraction. The extinction angle on b (010) was determined on carefully orientated plates, the measurements being made in sodium light and repeated a large number of times in order to give a correct average. In the majority of cases these plates were made from well-developed crystals, so that the direction of the inclination of the clino-axis was known. In all these cases the extinction direction c was found to lie, as is usual with amphiboles, in the obtuse angle β. In the case of the pleochroic varieties a second plate was prepared parallel to a (100) in order to give the vibration direction b. Below are summarized the results obtained, the corresponding analysis being given in the table on p. 181.

1. Tremolite from Richville, near Gouverneur, New York.
   $\alpha = 1{\cdot}5992$, $\beta = 1{\cdot}6132$, $\gamma = 1{\cdot}6246$. Mean index $= 1{\cdot}612$.
   $\gamma - \alpha = {\cdot}0254$.
   $2V = 83° 23'$. $c \wedge \dot{c} = 20° 1'$.
2. Tremolite from Lee, Massachusetts.
   $\alpha = 1{\cdot}6022$, $\beta = 1{\cdot}6192$, $\gamma = 1{\cdot}6347$. Mean index $= 1{\cdot}618$.
   $\gamma - \alpha = {\cdot}0325$.
   $2V = 86° 29'$. $c \wedge \dot{c} = 16° 38'$.
3. Actinolite from Russell, St. Lawrence Co., New York.
   $\alpha = 1{\cdot}6162$, $\beta = 1{\cdot}6304$, $\gamma = 1{\cdot}6412$. Mean index $= 1{\cdot}629$.
   $\gamma - \alpha = {\cdot}0250$.
   $2V = 81° 30'$. $c \wedge \dot{c} = 14° 47'$.
4. Actinolite from Greiner in Tyrol.
   $\alpha = 1{\cdot}6173$, $\beta = 1{\cdot}6330$, $\gamma = 1{\cdot}6412$. Mean index $= 1{\cdot}631$.
   $\gamma - \alpha = {\cdot}0277$.
   $2V = 81° 38'$. $c \wedge \dot{c} = 14° 59'$.
5. Actinolite from Pierrepont, St. Lawrence Co., New York.
   $\alpha = 1{\cdot}6237$, $\beta = 1{\cdot}6382$, $\gamma = 1{\cdot}6503$. Mean index $= 1{\cdot}637$.
   $\gamma - \alpha = {\cdot}0236$.
   $2V = 84° 8'$. $c \wedge \dot{c}$ impossible to measure because of wavy character of extinction.
   Pleochroism, a = almost colorless, b = faint yellow-green, c = faint bluish green.
   Absorption, $c > b > a$.
6. Actinolite from the mines of Kragerö, Norway.
   $\alpha = 1{\cdot}6280$, $\beta = 1{\cdot}6442$, $\gamma = 1{\cdot}6547$. Mean index $= 1{\cdot}641$.
   $\gamma - \alpha = {\cdot}0267$.
   $2V = 76° 58'$. $c \wedge \dot{c} = 13° 35'$.
   Pleochroism, a and b = pale brown, c = light green.
   Absorption, $c > b = a$.

7. Hornblende from Edenville, Orange Co., New York.
   $a = 1{\cdot}6583$, $\beta = 1{\cdot}6701$, $\gamma = 1{\cdot}6789$. Mean index $= 1{\cdot}668$.
   $\gamma - a = {\cdot}0206$.
   $2V = 81^\circ\ 42'$. $c > c = 23^\circ\ 48'$.
   Pleochroism, a and b = light brownish green, c = dark green.
   Absorption, $c > b = a$.
8. Hornblende from Renfrew, Ontario, Canada.
   Mean index $= 1{\cdot}67$. $c \wedge c = 33^\circ\ 20'$.
   Pleochroism, a and b = olive-green, c = dark blue-green.
   Absorption, $c > b > a$.
9. Hornblende from Mte. Somma, Italy.
   Mean index $= 1{\cdot}68$.
   Pleochroism, a and b = olive-green, c = dark blue-green.
   Absorption, $c \quad b = a$.
10. Hornblende from Cornwall, Orange Co., New York.
    Mean index $= 1{\cdot}71$. $c \wedge c = 9^\circ$.
    Pleochroism, a = light olive-green, b = yellowish green,
    c = bluish-green.
    Absorption, $c > b > a$.

	1	2	3	4	5	6	7	8	9	10
SiO_2	57·45	57·69	54·80	56·25	52·31	51·85	41·99	43·76	39·48	36·86
TiO_2	----	0·14	0·10	---	0·28	1·26	1·46	0·78	0·30	1·04
Al_2O_3	1·30	1·80	2·58	1·24	2·69	4·36	11·62	8·33	12·99	12·10
Fe_2O_3	0·18	0·00	2·50	0·78	3·09	2·58	2·67	6·90	7·25	7·41
FeO	0·22	0·55	4·75	5·50	6·68	5·46	14·32	10·47	10·73	23·35
MnO	0·07	tr.	tr.	0·48	0·70	0·35	0·25	0·50	1·00	0·77
MgO	24·85	24·12	20·30	21·19	19·27	19·48	11·17	12·63	11·47	1·90
CaO	12·89	13·19	12·08	12·08	11·88	10·60	11·52	9·84	12·01	10·59
K_2O	0·54	0·22	0·24	0·28	0·50	0·35	0·98	1·28	2·39	3·20
Na_2O	0·67	0·48	0·82	0.19	0·78	2·15	2·49	3·43	1·70	1·20
H_2O	1·16	1·56	1·60	1·81	1·42	1·21	0·61	0·65	0·76	1·30
F_2	0·77	0·37	0·77	0·04	0·93	0·46	0·80	1·82	0·05	0·27
Loss at 110°	0·09	0·10	0·11		0·08	0·13	0·08	0·10	0·12	
	100·19	100·22	100·65	99·84	100·59	100·24	99·96	100·49	100·25	99·99
$O=F_2$	0·32	0·15	0·32		0·39	0·22	0·33	0·76	0·02	0·11
	99·87	100·07	100·33		100·20	100·02	99·63	99·73	100·23	99·88

All analyses by Stanley except No. 10, which is by J. L. Nelson.

1. Tremolite from Richville.
2. Tremolite from Lee.
3. Actinolite from Russell.
4. Actinolite from Greiner.
5. Actinolite from Pierrepont.
6. Actinolite from Kragerö.
7. Hornblende from Edenville.
8. Hornblende from Renfrew.
9. Hornblende from Mte. Somma.
10. Hornblende from Cornwall.

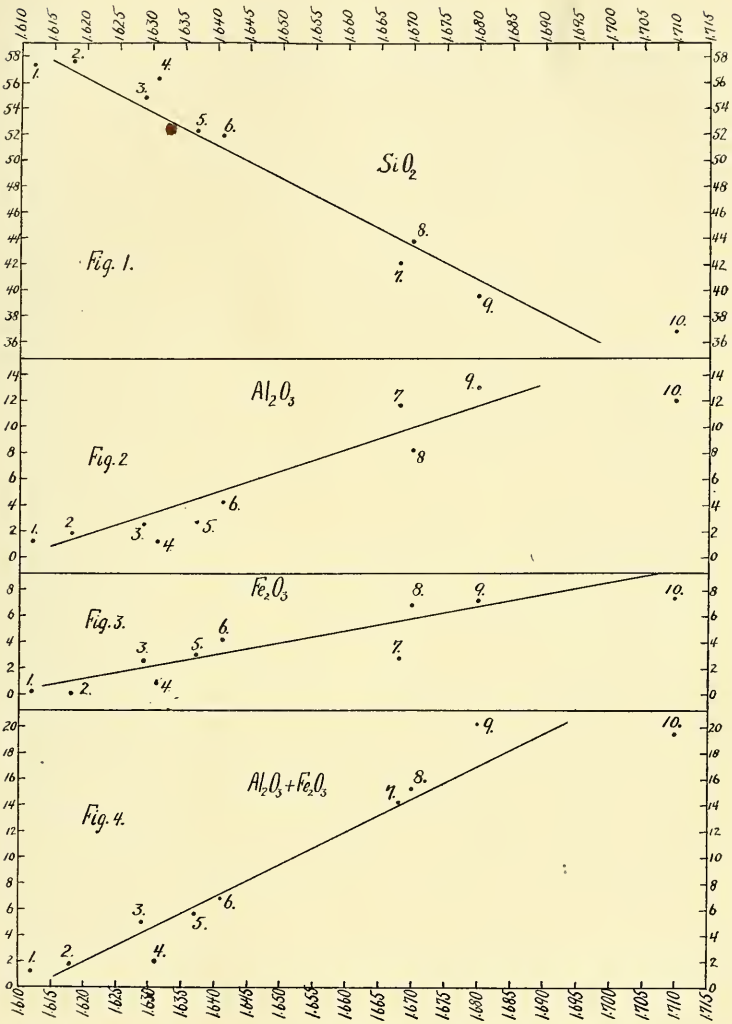
From the above facts it is possible to make the following general statements concerning the optical character of what may be called normal and typical amphiboles. The mean index of refraction ranges from about 1·61 to about 1·71. The mean index of refraction of typical tremolite lies between 1·61 and 1·62; that of typical actinolite ranges from 1·63 to

1·64; that of typical hornblende between 1·66 and 1·71. The birefringence of the whole series is about the same, the extremes observed being ·0206 in the hornblende from Edenville and ·0325 in the tremolite from Lee, the average of the series being ·0259. The axial angles as far as they could be calculated range from about 77° to 86° 30′. The extinction between c and *c* measured on *b* (010) ranges from 16° to 20° in tremolite, from 13° 30′ to 15° in actinolite and from 9° to over 33° in the typical hornblendes. Strong pleochroism was found only in the hornblendes, the actinolite members showing it but faintly, if at all. The absorption was always $c > b > a$, although frequently little difference could be distinguished in the color of the light vibrating parallel to a and b. The plane of the optical axes in these minerals was always in the symmetry plane and the bisectrix c lay in the obtuse angle β. The optical character, where it could be proven, was found to be uniformly negative.

With our present meager knowledge concerning the relations existing between chemical composition and optical characters, such general statements, as given above, are perhaps all that should be attempted. The amphiboles, because of the wide variation in their composition and the large number of variable radicals which they contain, present extraordinary difficulties to any exact correlation between the chemical and optical properties. Such a correlation it is quite possible can never be made. Yet it is thought, that within somewhat wide limits and with the recognition of numerous exceptions, a tentative correlation based on the work with this series of amphiboles can be given.

It was found on studying the above optical determinations in respect to the corresponding analyses that the variation in the mean index of refraction came nearer to showing a correlation with the variation in composition than any of the other optical characters. Consequently the analyses have been chiefly studied in the endeavor to discover, if possible, how they varied with increase in the value of the mean index of refraction. The analyses, as given on page 181, are arranged in order of the rise in the value of their mean indices of refraction. With the purpose of making these relationships clearer, figs. 1 to 9, which show them in graphical form, are given. In these figures the mean indices of refraction are shown as the abscissas while the percentages of the different radicals present in the minerals form the ordinates. The numbers given to the different points located on the figures correspond to those of the analyses on page 181. In each figure a straight line has been drawn which falls as closely as possible to the different points. Very likely a curve would have better expressed the relations between the indices of refraction and

Figs. 1–4.

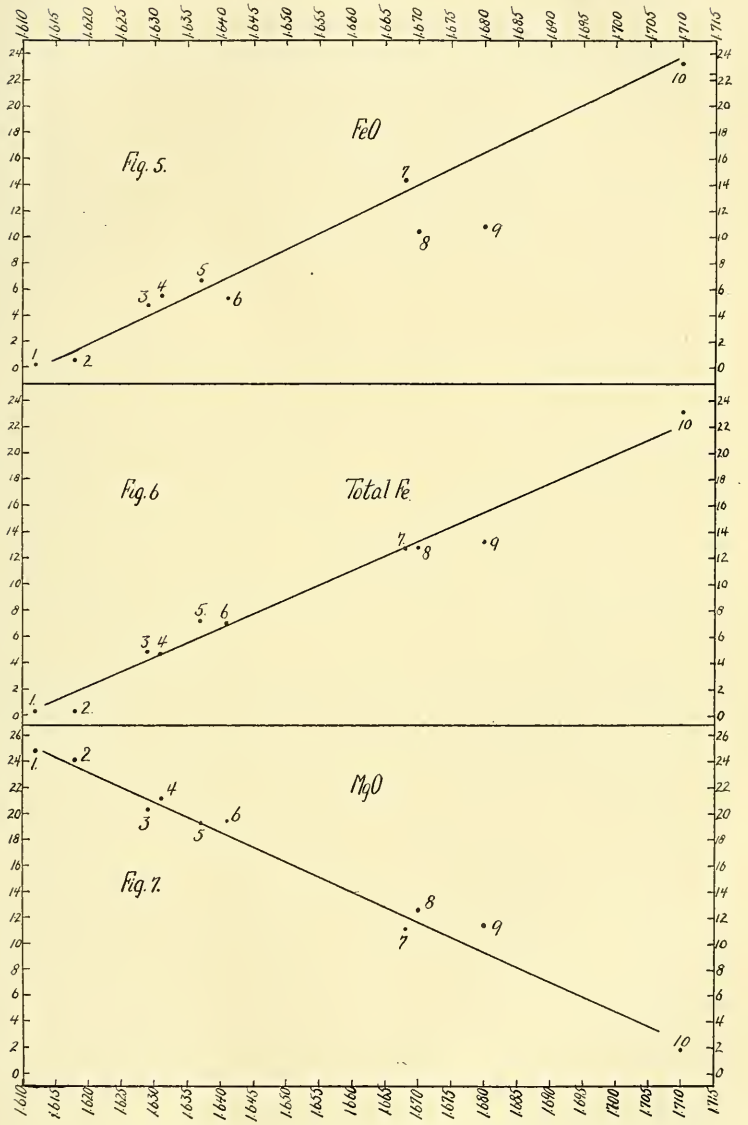


the percentage composition, but, with the data available, it seemed best to assume that this line was straight. It will be noted that the first six analyses form a series, the members of which lie close together. Then there comes quite a break, with analyses 7, 8 and 9 falling again in a group by themselves. There is another break and analysis 10 lies at the end by itself. It is unfortunate that other data were not available by means of which these gaps could have been closed.

Figure 1 shows the decrease in percentages of SiO_2 with the rise in value of the mean index of refraction. The relations here are reasonably well expressed by the straight line given in the figure. Of the first nine analyses, the one which departs farthest from this theoretical line is No. 4 and this is only about 2·5 per cent out of the way. In figure 2 the increase in the percentages of Al_2O_3 are shown corresponding to the increase in value of the mean refractive index. The points determined in this case show more general variation from the straight line than in the case of the silica, yet here the greatest variation among the first nine analyses is only a little over 2 per cent. Figure 3, which shows the variation in the percentages of Fe_2O_3, is much the same, the greatest variation being about 2·7 per cent in the case of analysis 7. Figure 4 shows the variation in the sum of Al_2O_3 and Fe_2O_3. As might be expected, the position of the points in this figure in general approximate much closer to the straight line than in the two previous figures, analyses 4, 9 and 10 being the only ones that depart from it in any notable dgree. Figure 5 shows the variation in amount of FeO with the increase in value of the index of refraction. Eight of the analyses give points that lie reasonably close to the line; analyses 8 and 9 however depart considerably from it, 9 being nearly 6 per cent out of the way. Strikingly different is the agreement shown in figure 6, in which the amounts of total iron are given. Here analysis number 9 is the only one that shows any notable discrepancy and the amount of variation in this case is only about 2 per cent. Figure 7 shows that the decrease in percentage of MgO follows closely the rise of the index of refraction, the greatest variation from the line being 2 per cent in the case of analysis number 9. Figure 8 gives the percentages of CaO in relation to the indices. There is a slight decrease in the amount of CaO as the index rises but the extreme variation is not much over 3 per cent. Consequently the influence of the lime upon the index of refraction must be fairly uniform throughout the series. Figure 9 gives the percentages of alkalies present, K_2O+Na_2O. They show a slight increase in amount with the rise of the indices, but as the largest amount of the alkalic oxides is under 5 per cent they cannot have much influence upon the optical characters.

From the above it can be seen that with this series of amphiboles it is the silica, the total iron and the magnesia that follow in their varying percentages most closely the variation in the mean index of refraction. It must be to them that this variation is chiefly due and in all probability the percentage of total iron present is the factor possessing the greatest influence. With full realization of the incompleteness upon which these

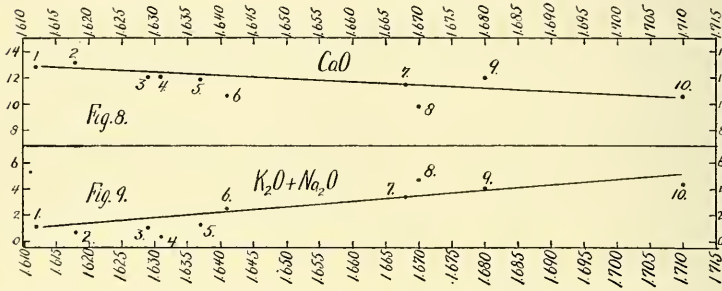
FIGS. 5–7.



figures are based and that there will be many exceptions found, yet, it is thought that by their use the composition of a normal and typical amphibole can be predicted within reasonable limits when its mean index of refraction is known.

It will be of interest to next consider two other amphiboles analyzed by Stanley, together with several described by other authors, in order to see how far they agree with those given above. As already stated, the literature shows surprisingly few cases of recent analyses with which a complete description of the optical properties are given. Unfortunately also for use in the present discussion, such amphiboles, as have been described, are for the most part exceptional in their nature

Figs. 8, 9.



since the interest in them, which led to their description, was naturally caused by their unusual character. Therefore, many of these analyses cannot be taken as belonging to amphiboles that could be considered normal and typical in character. Nevertheless it will be of value to consider them and endeavor to account for their divergence from the series given above.

Analysis 11 is of a tremolite from Switzerland. Its optical characters are given by Kreutz as follows: $\alpha = 1{\cdot}6000$, $\beta = 1{\cdot}6155$, $\gamma = 1{\cdot}6272$. Mean index $= 1{\cdot}6136$. $\gamma - \alpha = {\cdot}0272$. $2V = 85°\ 30'$ (calculated by present writer). This analysis will be found to answer closely to what would be expected, from the above study, to be the composition of an amphibole having its mean index of refraction.

Analysis 12 is of the unusual hornblende from Grenville township, Quebec, Canada, analyzed by Stanley. Its optical properties are as follows: $\alpha = 1{\cdot}6128$, $\beta = 1{\cdot}6180$, $\gamma = 1{\cdot}6328$. Mean index $= 1{\cdot}623$. $\gamma - \alpha = 0{\cdot}020$. $2V = 56°\ 8'$. $c \wedge \dot{c} = 29°\ 44'$. For a hornblende with its mean index of refraction, it is characterized by a very low percentage of silica, by a high amount of alumina, by low percentages of the oxides of iron and by high

percentages of the alkalies. It is especially distinguished by the unusual amount of fluorine that it contains (2·76 per cent). Another factor to be considered is the 1·2 per cent of TiO_2 which is present. The effect of an increase in the percentages of fluorine and the alkalies is generally thought to lower the indices of refraction and that of an increase of TiO_2 to be opposite in character. With all these constituents present in unusual amounts it is difficult to come to any reasonable conclusion concerning the correlation of the chemical and optical properties of this amphibole. The axial angle, diverging as it does so markedly from the usual value, shows clearly that this Grenville mineral is abnormal in character.

Analysis 13 is of the hornblende known as pargasite from Pargas, Finland. Its optical characters as given by Kreutz are as follows: $a = 1{\cdot}6158$, $\beta = 1{\cdot}6205$, $\gamma = 1{\cdot}6353$. Mean index $= 1{\cdot}6255$. $\gamma - a = {\cdot}0195$. $2V = 59° 30'$. $c \wedge \dot{c} = 27° 13'$. As Kreutz has pointed out, this mineral is closely analogous to the hornblende from Grenville described above. Like it, it is characterized by a low amount of silica, high percentages of alumina and alkalies and by the presence of a notable amount of fluorine (1·82 per cent). The extinction angle and the axial angle are also closely similar. Like the Grenville mineral it cannot be considered as normal in character.

Analysis No. 14 is of a hornblende from Chester, Massachusetts, described by Duparc and Pearce. Its optical properties are given as follows: $a = 1{\cdot}6598$, $\beta = 1{\cdot}6729$, $\gamma = 1{\cdot}6798$. Mean index $= 1{\cdot}6698$. $\gamma - a = {\cdot}0200$. $2V = 75° 44'$ (calculated by present writer). $c \wedge \dot{c} = 14° 40'$. This analysis agrees reasonably well with what might be predicted for an amphibole having its mean index of refraction. The amounts of silica and magnesia agree closely with the corresponding percentages to be derived from figures 1 and 7. The amount of sesquioxides and the total iron are somewhat higher than would be expected.

Analysis No. 15 is of a variety of amphibole called soretite, coming from Koswinsky in the northern Urals and described by Duparc and Pearce. Its optical character is as follows: $a = 1{\cdot}6627$, $\beta = 1{\cdot}6765$, $\gamma = 1{\cdot}6856$. Mean index $= 1{\cdot}6741$. $\gamma - a = {\cdot}0228$. $2V = 82° 30'$ (observed). $c \wedge \dot{c} = 17°$. Pleochroism, $\mathfrak{a}$ = pale greenish yellow; $\mathfrak{b}$ = green, $\mathfrak{c}$ = deep green. The analysis agrees quite closely with the theoretical one to be derived from consideration of the figures 1 to 9. The amounts of silica, alumina and magnesia are within less than two per cent of what would be expected. The percentage of ferric oxide is high and that of ferrous oxide correspondingly low, but the amount of total iron present is almost exactly that which would have been predicted from the study of figure 6.

Analysis 16 is of the basaltic hornblende from Bilin, analyzed by Stanley, the optical properties of which follow: Mean index = 1·692. $c \wedge \dot{c} = 1° 12'$ in the acute angle β. Pleochroism, a = light yellow-green, b = orange, c = dark reddish brown. Absorption, c>b>a. The percentage of silica present is about what would be expected from a hornblende with a mean index of refraction of 1·69. The sesquioxides are low, the amount of iron protoxide is very deficient and the magnesia is about double what would be expected. This hornblende contains 1·68 per cent of TiO_2, which undoubtedly has a marked influence upon its optical properties, although it would hardly seem sufficient to account for all its peculiarities. It is characterized optically by its unusual extinction angle and by the deep reddish brown color of the light vibrating parallel to c. This hornblende shows little correspondence with the series given above.

Analysis 17 is of the variety of amphibole known as kaersutite, from Kaersut, Greenland, as it is given by Washington. Its optical properties follow: $a = 1·676$, $\beta = 1·694$, $\gamma = 1·708$. Mean index = 1·692. $\gamma - a = ·032$. $2V = 82° 6'$. This is an unusual amphibole in that it contains over 10 per cent of TiO_2. As might be expected, the amount of iron present is small for an amphibole having this index of refraction. It obviously cannot be classed as a normal amphibole.

Analysis 18 is of the similar mineral from Linosa, also given by Washington. Its optical properties are given as follows: $a = 1·692$, $\beta = 1·730$, $\gamma = 1·760$. Mean index = 1·726. $\gamma - a = ·068$. $2V = 79° 54'$. This, like the Kaersut mineral, has a large percentage of TiO_2 (8·47 per cent). It differs in having higher percentages of the iron oxides and lower percentages of the alkalies. Optically it is distinguished by having the highest mean index of refraction and strongest birefringence of any of the amphiboles described in this paper.

From the foregoing study the following tentative conclusions may be drawn. Given a normal and typical member of the Amphibole Group, its composition can be predicted within reasonable limits from knowing its mean index of refraction. Of the various constituent oxides, the silica, lime and magnesia follow most closely in their variations the change in the index of refraction. The alumina varies more widely but does not seem to have a great effect upon the index of refraction. The iron oxides in a less degree also frequently show a variation from what might be expected, but on the other hand the total iron present shows a close approximation to the theory. The introduction of notable amounts of titanium, alkalies and fluorine produces marked changes in the optical character. The presence of titanium serves apparently to raise the index of refraction while the alkalies and fluorine tend to lower it.

	11	12	13	14	15	16	17	18
SiO_2	58·22	45·79	48·38	42·74	40·52	39·95	39·52	40·85
TiO_2	....	1·20	0·05	1·08	1·71	1·68	10·31	8·47
Al_2O_3	1·37	11·37	10·83	5·48	10·99	17·58	11·22	9·89
Fe_2O_3	0·04	0·42	0·76	11·92	9·64	7·25	1·22	8·85
FeO	0·61	0·42	1·56	11·46	9·83	2·18	8·81	3·96
MnO	0·04	0·39	0·04	0·06	tr.	tr.	0·06	0·12
MgO	23·97	21·11	20·78	11·60	11·82	14·15	13·31	12·47
CaO	12·95	12·71	12·24	12·72	12·33	11·96	10·93	12·16
K_2O	0·04	1·69	1·38	0·56	0·68	1·98	1·07	0·63
Na_2O	0·24	2·51	2·69	2·25	2·38	3·16	2·95	2·01
H_2O	2·17	0·67	0·91		0·50	0·41	0·59	0·19
F	0·17	2·76	1·82			0·03		0·28
						NiO 0·13		0·10
	99·82	101·06	101·44	99·69	100·40	100·46	100·00	99·98
O=F	0·07	1·16	0·76			·01		
	99·75	99·90	100·68			100·45		

11. Tremolite from Switzerland. Kreutz, Min. Mitt., xxvii, 251, 1908.
12. Hornblende from Grenville, Penfield and Stanley, loc. cit.
13. Pargasite from Pargas, Finland. Kreutz, Min. Mitt., xxvii, 249, 1908.
14. Hornblende from Chester, Mass., Duparc and Pearce, Bull. Soc. Min., xxxi, 119, 1908.
15. Soretite from Koswinsky in northern Urals. Duparc and Pearce, Bull. Soc. Min., xxvi, 131, 1903.
16. Hornblende from Bilin, Penfield and Stanley, loc. cit.
17. Kaersutite from Kaersut, Greenland. Washington, this Journal, xxvi, 198, 1908.
18. Kaersutite from Linosa, Washington, ibid., p. 192.

It was felt that with the data at hand it would be of value to discover, if possible, any regularity in the chemical changes that accompany the variation in the angle of extinction, $c \wedge c$, measured on b (010). Some sixteen analyses of normal amphiboles were used for this purpose. These analyses were arranged in a series with decreasing angles of extinction. It was at once seen that they could be divided into two distinct groups, each of which covered much the same range of variation in the extinction angles but were quite distinct from each other chemically. The first series showed extinction angles ranging from 20° to 8° with percentages of silica varying from about 58 per cent to 51 per cent. The second series showed a variation in extinction angles from about 33° to 9° with silica percentages from about 44 per cent to 36 per cent. That is, we may have two amphiboles of distinctly different composition, one belonging to the tremolite-actinolite group and the other to the hornblende group, which have nevertheless the same angles of extinction; compare, for instance, analyses IV and XIV, p. 190. These two series of analyses were separated from each other and each studied by itself.

The analyses of the tremolite-actinolite series are given on p. 190, arranged with decreasing angles of extinction. In

Tremolites and Actinolites.

	I	II	III	IV	V	VI	VII	VIII
SiO_2	57·47	57·69	55·02	56·25	54·80	55·21	51·85	54·52
TiO_2	----	0·14	----	----	0·10	----	1·26	0·39
Al_2O_3	1·28	1·80	4·53	1·24	2·58	3·45	4·36	9·25
Fe_2O_3	0·18	----	1·04	0·78	2·50	----	2·58	4·44
FeO	0·22	0·55	3·28	5·50	4·75	7·49	5·46	9·81
MnO	0·07	tr.	----	0·48	tr.	----	0·35	0·46
MgO	24·87	24·12	20·36	21·19	20·30	18·97	19·48	10·33
CaO	12·84	13·19	8·00	12·08	12·08	10·50	10·60	1·98
K_2O	0·49	0·22	1·52	0·28	0·24	----	0·35	0·16
Na_2O	0·68	0·48	6·71	0·19	0·82	2·45	2·15	7·56
H_2O	1·30	1·56	0·51	1·81	1·60	1·75	1·21	1·78
F	0·77	0·37	----	0·04	0·77	----	0·46	----
	100·19	100·22	100·97	99·84	100·65	99·82	100·24	100·68.
Total Fe	0·29	0·42	3·27	4·81	5·44	5·82	6·24	10·84
Extinction angle	20°1′	16°38′	16°16′	14°59′	14°47′	14°34′	13°35′	8°
Mean index	1·612	1·618	----	1·631	1·629	1·639	1·641	----

I. Richville, see p. 181. II. Lee, see p. 181. III. Széchenyite, see Krenner, Zs. Kr., xxxi, 502, 1899. IV. Greiner, see p. 181. V. Russell, see p. 181. VI. Berkeley, Blasdale, Bull. Univ. Calif., ii, 333, 1901. VII. Kragerö, see p. 181. VIII. Blasdale, Bull. Univ. Calif., ii, 338, 1901.

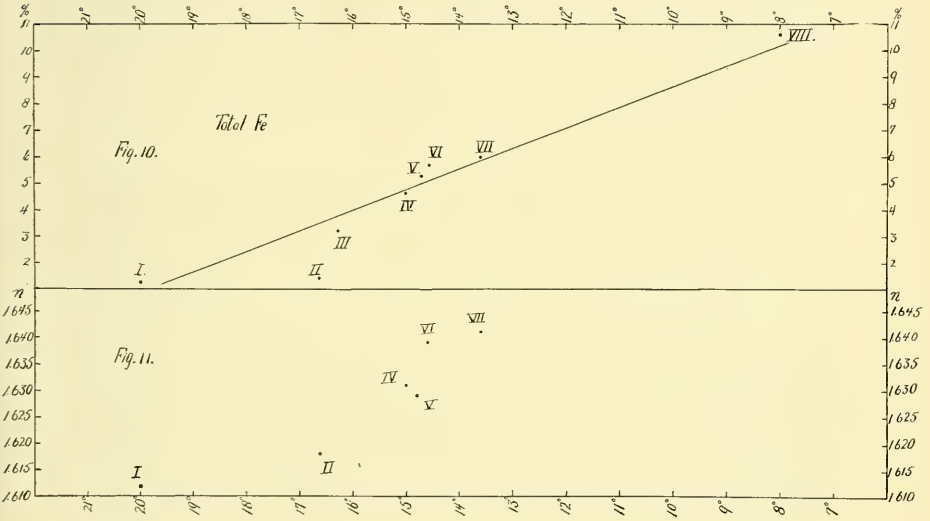
Hornblendes.

	IX	X	XI	XII	XIII	XIV	XV	XVI
SiO_2	43·76	41·99	43·35	40·52	45·20	39·58	42·74	36·86
TiO_2	0·78	1·46	----	1·71	0·84	tr.	1·08	1·04
Al_2O_3	8·33	11·62	8·11	10·99	7·34	14·91	5·48	12·10
Fe_2O_3	6·90	2·67	7·91	9·64	7·55	4·01	11·92	7·41
FeO	10·47	14·32	10·11	9·83	15·80	10·67	11·46	23·35
MnO	0·50	0·25	----	tr.	1·52	tr.	0·06	0·77
MgO	12·63	11·17	14·33	11·82	8·40	13·06	11·60	1·90
CaO	9·84	11·52	13·21	12·33	12·30	11·76	12·72	10·59
K_2O	1·28	0·98	1·87	0·68	0·37	0·62	0·56	3·20
Na_2O	3·43	2·49	2·18	2·38	0·80	2·87	2·25	1·20
H_2O	0·65	0·61	0·91	0·50	0·70	2·79	----	1.30
F	1·82	0·80	----	----	----	----	----	0·27
	100·49	99·86	100·98	100·40	100·82	100·27	99·69	99·99
Total Fe	12·98	12·99	13·38	14·38	17·35	11·09	17·24	23·33
Extinction angle	33°20′	23°48′	17°56′	17°	15° 9′	15°	14°40′	9°
Mean index	1·67	1·668	----	1·6741	----	----	1·67	1·71

IX. Renfrew, see p. 181. X. Edenville, see p. 181. XI. Artificial amphibole, Chrustschoff, Jb. Min., ii, 86, 1891. XII. Soretite, Duparc and Pearce, Bull. Soc. Min., xxvi, 126, 1903. XIII. Philipstadite, Daly, Proc. Am. Acad. Sci., xxxiv, 433, 1899. XIV. Piedmont, Van Horn, Am. Geol. xxi, 370, 1898. XV. Chester, Duparc and Pearce, Bull. Soc. Min., xxxi, 118, 1908. XVI. Cornwall, see p. 181.

general these analyses show, together with the decrease in the angle of extinction, a decrease in the percentages of SiO_2, MgO and CaO and an increase in the percentages of Al_2O_3, Fe_2O_3, FeO and the alkalies. This variation in composition is by no means regular and the relations existing between the composition and the angle of extinction are not at all clear. The only relationship that seems at all close in character is that between the angle of extinction and the total amount of iron present, there being an increase in the percentage of total iron

FIGS. 10, 11.



that follows closely the decrease in the extinction angle. The correlation between these two is shown graphically in figure 10. That the alkalies have little effect upon the angle of extinction is seen by comparison of analyses I and V and III and VIII. It will be noted further that the decrease in the value of the extinction angle is accompanied by a fairly uniform increase in the value of the mean index of refraction ; see figure 11.

The hornblende analyses are given on p. 190, also arranged in the order of decreasing extinction angles. These analyses have been studied in various ways but without finding any reasonable correlation between their percentage composition and the angle of extinction. The variations in the percentages

of the different oxides are quite irregular. The amount of total iron present increases in general with the decrease in the angle of extinction, yet this increase is irregular (note the low percentage of total iron shown in analysis XIV) and does not even begin to show the same degree of uniformity as in the case of the tremolite-actinolite series.

The fact that we can have two members of the Amphibole Group differing decidedly in their percentage composition but still showing the same angles of extinction proves at once that the value of the extinction angle does not depend directly at least upon the percentage composition. It seems probable that it must depend ultimately in a large measure upon the kind and amount of elements present in the mineral, but it is likely that it is also influenced largely by the character of the physical molecule into which they are grouped. The relationships here are certainly complex and the available data are far too few to allow us to hope that the problem can be solved as yet.

Various writers have previously attempted to find a correlation between the chemical and optical properties of the amphiboles. Murgoci in a study* which was concerned chiefly with the characters and classification of the glaucophane-like amphiboles makes, however, some general statements. On p. 362 he says: "The chemical constituent with the most influence on the physical properties seems to be Fe_2O_3 (viz. $Fe_2Si_3O_9$) and that not only in the glaucophane series, but in general in the amphibole family . . . Further, the size of the angle of the optic axes, the position of the axial plane and even the angle of extinction, up to a certain point, are in relation with the amount of Fe_2O_3." This may be true in respect to the alkali-rich amphibole-like glaucophane, but the facts as given above hardly bear this statement out in respect to the ordinary amphiboles. The amount of FeO shows a closer relation to the optical properties than the Fe_2O_3 and the amount of total iron present conforms more closely yet. Further, the same author states on p. 373 that "A comparison of the whole group of $AlFe'''$ amphiboles has convinced me that in general the size of the angle of extinction is related neither to the amount of Al_2O_3 nor to the amount of Fe_2O_3, but to the proportion of their molecular coefficients of combination in the amphibole constitution." A study of the analyses given above has failed to confirm this theory. In fact it only needs a hasty inspection of the relative percentages of Al_2O_3 and Fe_2O_3 in the analyses quoted on p. 190 to show that the assumption does not hold true with them.

* Contribution to the Classification of the Amphiboles, Bull. of the Geol. Dept. Uni. of Calif., iv, 359, 1906.

The fact that the iron content of an amphibole has a large influence upon the optical characters was stated as long ago as 1871 by Tschermak* and has recently been emphasized by Kreutz.† The results of the present study, as already given, bear out his statement.

Wiik‡ endeavored to show that the size of the extinction angle, $c \wedge \dot{c}$, increased as the percentages of Al_2O_3 increased. This theory has already been shown by others to be untenable and the results of the present study point to the same conclusion.

Mineralogical Laboratory of the Sheffield Scientific School,
Yale University, New Haven, Conn., July 2, 1913.

* Min. Mitt., p. 17, 1871. † Min. Mitt., xxvii, 250, 1908.
‡ Zs. Kr., vii, 79, 1883.

SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *The Action of Aluminium Carbide upon Solutions of Metallic Salts.*—Hilpert and Ditmar have found that aluminium carbide, which has the formula Al_4C_3 and which reacts with water and with acids giving methane, CH_4, is capable of methylating certain metals when it acts upon solutions of their salts. For instance, when aluminium carbide is placed in a hydrochloric acid solution of mercuric chloride, mercuric methyl chloride, $HgCH_3Cl$, is formed, and when the solution is neutral or slightly acid, mercury dimethyl, $Hg(CH_3)_2$, is produced. In the same manner bismuth trimethyl, $Bi(CH_3)_3$, which is otherwise difficult to obtain, can be synthesized. Tin salts also are methylated by aluminium carbide, and in this case the tin-methyl compounds, on account of their intense and characteristic odor, may be used as a qualitative reaction for tin, for even as small a quantity as 0·1 mg. of stannous or stannic chloride in 2 ccm. of dilute hydrochloric acid, upon boiling with a small quantity of aluminium carbide, gives a strong odor. Preliminary experiments have shown that not only arsenic and antimony can thus be methylated, but also other metals with which such compounds have not been previously obtained. For example, there is formed in the reaction between copper sulphate and aluminium carbide a compound with a disagreeable odor resembling mercury methyl. The exact mechanism of these interesting reactions is uncertain, and it is remarkable that the authors have not been able to methylate

any pure organic halide by means of this reaction. For instance, chloracetic acid could not be changed to propionic acid, nor benzyl chloride into phenylethane. It does not appear, however, that electrolytic dissociation is a requirement for the reaction, for mercuric cyanide reacts like the chloride.—*Berichte*, xlvi, 3738.

H. L. W.

2. *Solubilities at the Critical Temperatures of Solvents.*—Fritz Friedrichs has made experiments with a large number of substances, mostly inorganic salts, by placing them in sealed glass tubes with liquid anhydrous ammonia and also with liquid sulphur dioxide, and then heating the tubes to the critical temperatures of the liquids. Although the continuity of the liquid and gaseous condition of solutions has been observed previously, Friedrichs has made an interesting contribution to our knowledge of the solubility of salts in the two liquids used for his experiments. For example, the fact that potassium iodide dissolves readily in liquid ammonia and passes into the gaseous state with the ammonia at the critical temperature of the latter is striking, as is also the similar behavior of dilute solutions of silver iodide in the same solvent. It would be interesting to find to what extent such gaseous solutions of solids could be expanded, and still hold non-volatile solids in solution. H. L. W.

3. *Organic Chemistry for Advanced Students;* by Julius B. Cohen. Vol. II, 8vo, pp. 427. New York, 1913 (Longmans, Green & Co. Price, $4.50 net).—The first volume of this very useful text-book was published in 1907. The present volume fills up gaps left in the first one according to the author's present plan of presenting the subject in his lectures. The course as modified gives more attention to the physical side of organic chemistry than was the case with the first volume. The chapters of the book deal with the valency of carbon, the nature of organic reactions, dynamics of organic reactions, physical properties and structure, and color and structure. The book makes an excellent addition to the first volume. H. L. W.

4. *Industrial Chemistry for Engineering Students;* by Henry K. Benson. 12mo, pp. 431. New York, 1913 (The Macmillan Company. Price, $1.90).—The purpose of this text-book is to describe from the standpoint of chemistry the more common materials used in the various branches of engineering. The topics of greatest interest in engineering, such as fuels and combustion, clay products and cement, are treated more fully than others. There are short chapters on the manufacture of pig iron, the commercial forms of iron and steel and industrial alloys, but no other metallurgical subjects are treated. The references to the literature of the subjects that are included are very extensive and valuable, and the book appears to give a very good presentation of the subjects for the purpose in view. As the book does not touch upon many important chemical industries it is hardly suitable for students of chemistry and chemical engineering. The book appears to be lacking in the critical discussion of

many of the materials described. For instance, little is said about the relative merits or the prices of the various pigments, oils, resins and solvents used in the manufacture of paints and varnishes, although many of them are described. H. L. W.

5. *Outlines of Theoretical Chemistry;* by FREDERICK H. GETMAN. 8vo, pp. 467. New York, 1913 (John Wiley & Sons). —This text-book is designed for classes beginning the study of theoretical or physical chemistry. A working knowledge of elementary chemistry and physics is presupposed in the presentation of the subject, although an introductory chapter of 19 pages is devoted to a brief review of the principles with which the student is assumed to be fairly familiar. These elementary principles include the laws of definite, multiple, and combining proportions, the atomic theory, Avogadro's hypothesis, atomic heats, isomorphism, valence, and atomic weights, while the main part of the book is advanced and physical in its character. The presentation is mathematical in its aspect, but the use of calculus has been restricted as far as possible. A good feature is the introduction of many numerical problems for solution by the student. There is a chapter on the electron theory, but the author, unfortunately it appears, has decided against the incorporation of any account of radiochemistry. H. L. W.

6. *Oxygen in the Sun.*—In the year 1896 Runge and Paschen showed that the first triplet of the principal series of the oxygen spectrum agreed in wave-length and relative intensity with three Fraunhofer lines in the solar spectrum. Since there are good reasons why the remaining oxygen lines would not be susceptible of detection in the solar spectrum, the coincidence and character of the members of the triplet have been accepted as sufficient proof that oxygen is present in the solar atmosphere. On the other hand, in 1912 Geiger obtained three lines in the arc spectrum of iron which agreed exactly with the triplet and which he ascribed to iron. If the lines observed by Geiger really owe their origin to iron then the argument of Runge and Paschen is not tenable because experience shows that, when sufficiently high dispersion and spectroscopic resolving power are used, the separate lines of different elements do not coincide exactly, much less in groups.

In order to settle the question as to the origin of this triplet the experimental side of the problem has been taken up again by RUNGE and PASCHEN. These investigators employed a Rowland concave grating of 3 meters radius of curvature in conjunction with a concave reflector which sent plane waves upon the grating. By working near the principal normal to the grating a non-astigmatic image of the slit was formed on the photographic plate. Furthermore, by using a photographic objective a non-astigmatic image of the source of light was thrown on the slit of the spectrograph. The first source used was a vertical arc between iron electrodes, the lower rod being the anode. The condensing lens was moved by hand in such a manner as to keep

the image of the intensely white spot on the oxide globule, from which the arc starts, focused exactly on the slit. The spectrogram shows that the members of the triplet in question extend only a relatively short distance from the globule, whereas the remaining iron lines recorded by Geiger extend across the entire field of view and are most intense in the region corresponding to the arc proper. No difference in the appearance of the triplet was observed when the voltage was changed from 220 to 60. These lines also were present near the anode when the arc was burned in air at a pressure of 1^{cm} of mercury. On the other hand, when a small piece of iron wire was laid on the positive electrode of a carbon arc, in air at atmospheric pressure, the triplet could not be found, notwithstanding the fact that all the other lines recorded by Geiger were photographed. When the processes of oxidation and reduction which occur in the arc between iron electrodes are taken into account together with the conditions which hinder oxidation in the carbon arc, little doubt can remain as to the oxygen origin of the triplet. The wave-lengths of the lines are given as 7772·01, 7774·21 and 7775·50 Å. U.

The proof seems to be made final and conclusive by the following argument of the authors. The "frequencies" of the lines are 12866·68, 12863·04, and 12860·91 so that the first differences become 3·64 and 2·13. The mean frequency differences of the remaining triplets of the oxygen spectrum are 3·70 and 2·08. Corrections to the frequencies of the lines of the first triplet would only have to be +0·02, −0·04, and +0·01 respectively in order to give the mean values just quoted. The corresponding corrections to the wave-lengths would be −0·012, +0·024, and −0·006 Å. U., all of which lie within the limits of experimental error. Therefore, it is clear that the triplet belongs to oxygen and that the evidence for the presence of this element in the solar atmosphere has been strengthened as a consequence of the apparent mistake of Geiger.—*Physik. Zeitschr*, No. 25, p. 1267, Dec. 1913. H. S. U.

7. *Fluorescence of the Vapors of Sulphur, Selenium and Tellurium.*—Although the number of fluorescent compounds is comparatively great, nevertheless the number of chemical elements which have been shown to possess this property, in the vapor state, is relatively small. In fact, prior to the latest work of W. Steubing, the following list was probably complete, namely: Sodium, potassium, rubidium, mercury, thallium, oxygen, bromine and iodine. In the case of oxygen it was found by Steubing that the fluorescent light, as well as the exciting radiation, had wave-lengths less than 2000 Å. U., that is, they fell within the Schumann region so-called. By analogy with the behavior of the vapors of the elements of the first group of the Mendelejeff table one would expect the heavier elements of the sixth, or oxygen group, to exhibit fluorescence having wave-lengths greater than 2000 Å. U., and hence to be susceptible of investigation with ordinary spectroscopic apparatus. Further-

more, the maximum of fluorescence should shift toward the red as the atomic weight increases.

These expectations have been realized by the recent work of Steubing. The details of the apparatus used will not be discussed in this place ; suffice it to say that the elements were vaporized in specially designed quartz vessels which were heated by means of either a Bunsen flame or a helix of wire carrying an electric current. For sulphur the exciting light was derived from an iron arc of about 5 amperes and 220 volts, while for selenium and tellurium an ordinary carbon arc sufficed. For selenium, and especially for sulphur, it was necessary to have the element in as pure a condition as possible, and hence great care had to be taken to exclude foreign gases from the quartz cylinders. On the other hand, the fluorescence of tellurium vapor was not very sensitive to the presence of impurities. The most important remaining facts discovered by Steubing may be summarized in the following words : (1) The four elements of the sixth column of the periodic system exhibit fluorescence in the vapor state. (2) As the atomic weight increases the fluorescence spectrum as a whole is displaced from the shorter towards the longer region of wave-lengths. (3) The region of excitation lies, (*a*) for oxygen, below 2000 Å. U., (*b*) for sulphur, between 2500 and 3200 Å. U., (*c*) for selenium, above 3000 Å. U., and extends into the visible spectrum, (*d*) for tellurium, in the more refrangible part of the visible region. (4) In order to obtain fluorescence it is necessary for the vapor to have a definite density and a definite temperature. This is especially true in the case of sulphur, for which the vapor must be superheated between 400° C. to 500° C. (5) The fluorescence spectra are discontinuous and consist of more or less "washed-out" groups of lines which appear to be bands.—*Physik. Zeitschr.*, No. 18, p. 887, Sept., 1913. H. S. U.

8. *The Series Lines of Neon.*—In the year 1911 Watson published an account of his unsuccessful attempt to discover line series in the spectrum of neon. He only found, among the relatively strong lines, several groups which repeated themselves with constant frequency difference. Recently R. Rossi has subjected Watson's wave-lengths to careful scrutiny and discovered three series among the faint lines. Two of the series lie entirely in the visible spectrum and are composed of doublets with constant frequency difference (167·5) between the members of the pairs. Since these two series also converge towards the same limit, 4119·8 Å.U., they resemble subordinate series. Nevertheless all efforts to find the associated principal series have failed. Furthermore, the neon series do not correspond to any of the subordinate series of helium, for, although the neon series are nearer to the red end of the spectrum than the helium series, as would be expected, the approximate relation between the separation of the doublets and the square of the atomic weight is not fulfilled. Rossi uses Rydberg's formula because the number of lines found for each series is small, namely, seven doublets in the

one series and four in the other. The third series calculated by Rossi consists of single lines all of which fall within the ultra-violet region. Finally, by using a quartz "end-on" spectrum-tube with neon at a pressure of about 4 mms., five new lines were discovered having respectively the following wave-lengths and intensities: 2352·0 (0), 2396·5 (2), 2464·0 (1), 2639·9 (1), and 2660·0 (0).—*Phil. Mag.*, vol. xxvi, Dec., 1913, p. 981. H. S. U.

9. *The Mass of Rapidly Moving Electrons.*—It is a matter of great theoretical importance to obtain experimental data which will enable a final decision to be reached concerning the relative merits of the theories of Abraham and Lorentz-Einstein. As is well-known, the experimental data of Bucherer and Wolz favored the longitudinal contraction of swift electrons as assumed in the theory of Lorentz, but Bestelmeyer has raised objections which cannot be disregarded. One of Bestelmeyer's adverse criticisms of the work of Bucherer and Wolz is that the number of experimental data obtained by these investigators is too small to justify the conclusion that Abraham's theory of a rigid, spherical electron is untenable. This objection has been removed by the recent work of Günther Neumann which was carried out at Breslau under the direction of Clemens Schaefer.

The method of crossed fields was employed. The apparatus formerly used by Bucherer was borrowed and partly remodeled. Twenty-six negatives were selected for the final calculations. The speeds of the electrons emitted by the radium salts varied from 0·4 to 0·8 of the speed of light. For each speed observed, the values of $\frac{e}{m_0}$ (for small speeds) were calculated by aid of the formulæ deduced on the theories of Abraham and Lorentz-Einstein. The resulting values of $\frac{e}{m_0}$ are plotted as ordinates on a diagram having as abscissæ the ratio of the corresponding electronic speed to the speed of light. The points derived from the formula of Lorentz fall close to a straight line parallel to the axis of abscissas, whereas the points pertaining to the hypothesis of Abraham show a systematic deviation from a constant value of $\frac{e}{m_0}$ as the speed increases. Also Bucherer's data give points which lie almost exactly on the mean straight line representing Neumann's experimental results. Between 0·4 and 0·7 of the speed of light the theory of Lorentz-Einstein is verified to about 1·5 parts in a thousand. Because of the ever increasing experimental difficulties as the speed of light is approached, the verification is not quite so good in the interval 0·7 to 0·8. On the other hand, the *curve* representing the hypothesis of Abraham consistently approaches the axis of abscissas until, at the speed-ratio 0·8, a deviation of about 8 per cent from the value of $\frac{e}{m}$ at low speeds is attained. It is therefore clear that the work of Neumann has

settled the question in favor of the theory of Lorentz. Finally, the weighted mean value of $\frac{e}{m_0}$ deduced by Neumann from his experimental data is given as 1·765 E. M. U., which agrees remarkably well with the average value of the results obtained by other investigators and by other sources of radiation.—*Physik. Zeitschr.*, No. 22/23, Nov., 1913, p. 1117. H. S. U.

II. Geology and Mineralogy.

1. *Changes in Level in the Earth's Crust;* by Osmond Fisher. (Communicated.)—In the addendum to a paper by me, on "a suggested cause of changes of level in the earth," published in the March number, 1906, of this Journal (vol. xxi, p. 216), I referred to a paper by Col. Burrard, Surveyor General of India, published in the Transactions of the Royal Society. In that paper Col. Burrard called attention to the "astonishing" difference of 0·103^{cm} between the value of gravity at Dehra Dun as determined by Basevi and Heaviside and that about 30 years later by Capt. Lenox-Conyngham. From this difference I argued that there had been a change of density beneath that station in the interval.

However, in a note to a reply to some criticisms of mine upon his theory of mountains, Col. Burrard now says, that the change referred to is apparent only, and was due to the vibration of the brick pillars on which Basevi's pendulum was swung.

Mr. Oldham, late of the Geological Survey of India, has now examined this question, and on referring to Gen. Walker's account of the "Operations" of the Survey, 1879, he finds that Basevi made two sets of observations at Dehra Dun. In the first, his second's pendulum was swung on a wooden support, standing on a concrete floor. The result of this set of observations agrees fairly well with Lenox-Conyngham's. Subsequently Basevi made a second set of observations at Dehra Dun, in which his pendulum was swung on brick pillars and the result obtained differed from the former, and he seems to have considered the value so obtained as the more trustworthy. It was to this latter result that Col. Burrard referred in his paper at the Royal Society, which I quoted.

It now appears that Lenox-Conyngham, who swings his half-second's pendulum on brick pillars, has found that a correction is necessary to allow for the vibration of the pillars, and there can be little doubt but that Basevi's second set of observations was vitiated by a like cause. Consequently, as Col. Burrard now says, the change of gravity, deduced by comparing Basevi's value quoted with that lately obtained, is apparent only. Nevertheless, there does seem to be some reason to think that small changes in the value of gravity are at present going on at Dehra Dun, as reported in "Nature," in a note, vol. xci, p. 143, 1913.

Graveley, Huntingdon, Nov. 20, 1913.

2. *Meteorites vs. The Earth;* by Oliver C. Farrington. (Communicated.)—The criticism by Merrill* of the writer's comparison of the composition of meteorites and the earth suggests to the writer some further observations. With Merrill's view, that the average compiled by him, by omitting the metallic iron and associated metals and sulphides from the sum of meteorite compositions, is "the most acid phase conceivable" for a meteoritic magma, the writer can hardly agree.

The quantity of unknown matter of the earth so greatly exceeds that of the known, that in comparing meteorites with the known matter of the earth only a few meteorites need be taken. Assuming a knowledge of the composition of the earth to a depth of ten miles,† and regarding the mean diameter of the earth as 7913 miles, the unknown substance of the earth exceeds the known in the ratio of 131:1. Hence only 4 of the analyses, numbering 443 in all, which were used by the writer to obtain an expression for the composition of the earth,‡ need be used to represent the composition of the earth's crust. Such a sum, moreover, would have the advantage of being derived from actual analyses rather than from a secondary treatment of them. For these four, in order that only well-known and representative meteorites may be taken, those of Juvinas, Frankfort, Petersburg and Stannern, as given in the writer's list, may be used. The average of these calculated to 100 is shown below and, for comparison, Washington's average for terrestrial rocks and Merrill's Table V.

	I	II		III
	Four Meteorites	Washington's average of terrestrial rocks		Merrill's Table V
SiO_2	49·85	58·24		45·46
Al_2O_3	11·14	15·80		3·21
Fe_2O_3, FeO	18·87	7·21		---, 19·29
MgO	9·83	3·84		26·86
CaO	9·44	5·22		2·06
Na_2O	0·63	3·91		1·11
K_2O	0·14	3·16		0·38
H_2O	---	1·79	MnO	0·65
TiO_2	0·03	1·04	Cr_2O_3 + Fe_2O_3	0·98
P_2O_5	0·07	·37		---
	100·00	100·58		100·00

That a magma of the composition shown in Table I might differentiate into the present rocks of the earth's crust seems to the writer entirely conceivable. Differentiations much greater in

* This Journal, (4), xxxv, 324, 1913.
† Clarke's assumption, Bull. U. S. G. S., 491, p. 22.
‡ Publ. Field Museum, Geol. Ser., vol. iii, p. 213, 1911.

kind occur among observed rocks of the crust, and it is not difficult to conceive that differentiation on a profounder scale in the early periods of the earth's history could have produced the crust of the present time from a magma like the above.

The view of Merrill that the excess of iron and magnesium in the older rocks is altogether the result of secondary accumulation seems also to the writer open to question. If time is the only factor necessary for the accumulation of metals and their compounds, it would seem that all metals and their salts should show preponderance in the early rocks. As is well known, this is not the case. That the two metals most abundant in meteorites should also be most abundant in the early rocks is *prima facie* evidence in favor of the excess of these metals at that time. Even if the Lake Superior iron deposits can be shown to be the result of secondary accumulation, it should be borne in mind that these are but a part of the iron deposits of early periods. The great bodies of magnetite of Laurentian age in the Adirondacks and Canada appear to be of primary origin. Important iron deposits in Norway are reported to be magmatic segregations of Archean granite rocks. The great iron deposits of Sweden are connected with early eruptive rocks, and so, too, are large ones of the Urals. It seems doubtful, therefore, whether the excess of iron in the older rocks can be altogether explained by the theory of secondary accumulation.

With regard to the origin of dolomite, it is probably true that the view that it is formed by the gradual replacement of lime by magnesia through the downward percolation of magnesian waters is a generally accepted one, but it is hoped that this will not prevent acceptance of another theory if satisfactory evidence can be presented in behalf of it. Several students of the subject have of late given excellent reasons for dissatisfaction with the replacement theory, and other methods of origin are being sought. One of the most complete of the recent summaries is by Steidtmann,* who after an extensive study expresses the view that "the occurrence of dolomites of vast thickness and extent cannot find a ready explanation in the mutative agency of underground waters." A similar view is expressed by Daly.†

That the sea, and therefore the limestones formed in it, are steadily becoming more calcic and less magnesian on account of the greater solubility of lime salts, is clearly shown by Steidtmann in the article mentioned. The highly magnesian nature of crinoid tests, as shown by analyses,‡ seems to the writer a further indication of this change. In a more magnesian ocean such forms could flourish in great abundance and become important rock-forming agents, but as the amount of magnesia diminished they gradually became extinct.

* Jour. Geol., xix, 342, 1911.

† This Journal, (4), xxiii, 109, 1907.

‡ H. W. Nichols, Pub. Field Col. Mus., Geol. Ser., iii, 49, 1906; Clarke, Bull. 491, U. S. G. S., p. 540.

3. *The San Franciscan Volcanic Field;* by HENRY HOLLISTER ROBINSON; Professional Paper No. 76, U. S. Geol. Surv., 8vo, pp. 213, maps and figs., 1913.—The San Francisco Mountains, so-called, in Arizona have in recent years become well known as they are situated beside the tourist route to the Grand Canyon of the Colorado. In addition to the prominent central mass of San Francisco Mountain there are a number of other peaks situated in its vicinity or at no great distance from it, the whole constituting a distinct field of volcanic activity on this portion of the great plateau. It is of this volcanic group that Dr. Robinson here presents the results of extensive studies in the field and of the material collected by him in the laboratory. The result forms one of the most detailed investigations of an extinct volcanic group which has yet been undertaken in this country.

After the introduction and a general consideration of this region, the author gives an account of the sedimentary platform upon which the volcanoes have been built, and then takes up the general geology of the volcanoes and lava fields. He shows that there were three general periods of volcanic activity, beginning with outflows of basalts, followed by the formation of the volcanic cones, and ending with another outbreak of basalt, forming a great number of small cones and of flows.

The second period presents the most complex stage of volcanic activity, as the cones in general are built up of various kinds of lava. Thus at San Francisco Mountain five stages of eruption, each yielding a different type of lava, have been worked out. The geology of each of the main peaks is described in detail, first with San Francisco Mountain, the main cone of the district, followed by Kendrick Peak, Bill Williams' Mountain, O'Leary Peak, Sitgreaves Peak, and Mormon Mountain. In addition to these cones the author shows that in the second period there were also intrusions of peculiar laccoliths, which were not only intrusive, but also partly extrusive in nature.

The succeeding portion of the work is devoted to presenting the results of the petrographic study of the lavas and of the general petrology of the district. The different kinds of rocks, rhyolites, dacites, latites, andesites, and basalts, have been thoroughly investigated, and their description is accompanied by numerous chemical analyses made by the author. Under the heading of the petrology there is given a series of statistical studies of the results afforded by the chemical analyses, affecting the origin and differentiation of the lavas, from various points of view. The author here comes to some very interesting conclusions which have a bearing on the general petrology of igneous rocks, but it would be beyond the scope of this review to present and discuss them. The whole work forms an important contribution not only to our knowledge of the geology of this part of the country, but also to the subject of theoretic petrology in general, and the final conclusions which Dr. Robinson has drawn from the results of his studies should be read by all petrologists.

L. V. P.

4. *The Devonian of Maryland.* Geological Survey of Maryland, 3 vols., with 1280 pages and 171 plates.—This great work treating of the entire Devonian of Maryland was begun about fifteen years ago, since which time it has grown to unforeseen proportions. The Lower Devonian (pp. 1–560, 98 plates) is the work of C. K. Swartz, Charles Schuchert, C. S. Prosser, E. O. Ulrich, R. S. Bassler, T. P. Maynard, D. W. Ohern, and R. B. Rowe. The Middle Devonian (pp. 1–338, 40 plates) is by C. S. Prosser, E. M. Kindle, E. O. Ulrich, R. S. Bassler, and C. K. Swartz; while the Upper Devonian (pp. 339–701, 33 plates) is by C. S. Prosser, C. K. Swartz, and John M. Clarke.

Of the fossil forms discussed, there are 785, of which 397 (142 new) are from the Lower Devonian, 185 (21 new) are from the Middle Devonian, and 203 (60 new) are from the Upper Devonian. These fossils occur in the following formations:

Lower Devonian—			
Helderberg formation,	thickness	290– 350	feet
Oriskany formation,	"	50– 417	"
Middle Devonian—			
Romney formation,	"	600– 1650	"
Upper Devonian—			
Jennings formation,	"	3400– 4750	"
Catskill formation,	"	1200– 3800	"
	Total thickness,	5540-10,967	feet

This storehouse of information, together with the Palæontology of New York, will be the mecca to which all students of the paleontology and stratigraphy of the Devonian in eastern America must go. We extend our hearty congratulations to State Geologist William Bullock Clark upon the completion of this model report on the Devonian of Maryland. C. S.

5. *Stratigraphy and Paleontology of the Alexandrian Series in Illinois and Missouri, Pt. I;* by T. E. Savage. Illinois Geol. Surv., Bull. 23, pp. 1–124, pls. I–VII, 1913.—A careful, detailed, and well-illustrated study of the basal Silurian formations of southern Illinois, with a description of the faunas of the two lowermost members, the Girardeau (28 species, 12 new), and Edgewood limestones (59 species, 36 new, and the new coral genus *Calvinia*). In northern Illinois occurs the Channahon limestone, which is correlated with the Edgewood; of the 23 species (12 new) found in the former series, 8 are also found in the Edgewood; but the general aspects of the two faunas are more harmonious than the figures indicate. C. S.

6. *On the important part played by calcareous Algæ at certain geological horizons, with special reference to the Palæozoic rocks;* by E. J. Garwood. Geol. Mag., dec. v, vol. x, pp. 440–446, 490–498, 545–553, 1913.—Because of the marked interest that is now being manifested the world over in the important rôle played by

the calcareous algæ in the formation of limestones and other calcareous strata, attention is directed to this important paper, delivered by Professor Garwood as his Presidential Address before the Geological Section of the British Association for the Advancement of Science, at the Birmingham meeting. The more important literature on the subject is referred to in the paper.

C. S.

7. *The Geological Survey of Oklahoma.*—At a meeting of the State Geological Commission of Oklahoma, late in December, the resignation of D. W. Ohern as Director of the Oklahoma Geological Survey was accepted. L. C. Snider, the assistant director, declined to consider the directorship and C. W. Shannon, field geologist, was appointed director. The personnel of the scientific staff of the Survey as now constituted is as follows: C. W. Shannon, director; L. C. Snider, assistant director; L. E. Trout, field geologist; Wm. A. Buttram, chemist.

8. *Minéralogie de la France et de ses Colonies;* per A. Lacroix. Tome cinquiéme; Deuxième Supplément et Index Géographique. Pp. 501. Paris 1913 (Librairie Polytechnique).—This is the second supplement to the exhaustive work by Professor Lacroix. It is chiefly given to a geographical index of localities with the species occurring at each. The places are arranged alphabetically under the countries, France, Alsace, Belgium, etc.; also Algeria and other French colonies, the most important of which from the mineralogical standpoint is Madagascar. The interesting new species from this remarkable island with notes on some other minerals are described briefly in the opening pages.

9. *Handbuch der Mineralogie;* von Dr. Carl Hintze. Erster Band, Lieferung 16; pp. 2401–2560. Leipzig, 1913 (von Veit & Comp.).—Begun in 1899, the Mineralogy of Hintze has now reached its twenty-eighth part. The minute, careful labors which the author has devoted to this great work are beyond praise. The present part is given to the fluorides, the species fluorite occupying much of the space.

III. Miscellaneous Scientific Intelligence.

1. *The Semi-Centennial Anniversary of the National Academy of Sciences, 1863–1913.* Pp. vii, 108, with illustrations. Washington, 1913.—A memorial volume, giving a history of the first fifty years of the National Academy of Sciences, was published some six months since and noticed in this Journal at the time (see vol. xxxvi, p. 185). The semi-centennial anniversary meeting, held in Washington in April, was an occasion of great interest not only to the Academy itself but also as regards American science in general. We have now an account of this April meeting prepared by the Home Secretary, Dr. Arthur L. Day, which gives in detail the

exercises of the three days concerned. The volume opens with a copy of the official program, following which is the introductory address of President Remsen. Other formal addresses by distinguished men especially invited for the occasion follow. These include President A. T. Hadley, who spoke on the relation of science to the higher education in America; Professor Arthur Schuster, on international coöperation in research; Dr. George E. Hale, on the earth and sun as magnets; and Professor J. C. Kapteyn, on the structure of the universe. The remarks of Dr. Woodward and President Wilson on the occasion of the distribution of medals, are given in full. The meeting closed with a dinner for the members of the Academy and invited guests, and the secretary is able to give here the complete speeches by the various gentlemen called upon by Dr. Woodward, the toastmaster. These were Vice President Thomas R. Marshall, Hon. James Bryce, the late Dr. S. Weir Mitchell, Dr. W. W. Keen, and Hon. Theodore E. Burton. These speeches, with the remarks of the toastmaster himself, form one of the most interesting features of the present volume, which closes with the register of those in attendance.

2. *Annual Tables of Constants and Numerical Data, chemical, physical, and technological, published by the International Commission of the VII and VIII International Congresses of Applied Chemistry.*—Volume III of these tables is now in press and will be issued in the first half of 1914. A descriptive circular with references to reviews of previous volumes may be secured on application to the University of Chicago Press. The subscription to volume III, now opened, will be closed March 31, 1914. The names of subscribers should be sent to the University of Chicago Press, to which subscriptions are payable at the time of publication. The price of volume III (as for volume II) is $6 unbound, $6.80 bound (carriage free). Members of contributing societies (the National Academy of Sciences, the American Academy of Arts and Sciences, the American Chemical Society, the American Electrochemical Society, the Society of Chemical Industry) and of contributing manufacturing establishments are entitled to a discount of 20 per cent (but not on the binding) provided their subscriptions are received by March 31, 1914. After March 31 the price will be $6.40 (unbound) and $7.20 (bound), with a charge for carriage; no discounts will be allowed.

The Commissioners for the United States are: Julius Stieglitz, University of Chicago; Edward C. Franklin, Leland Stanford University; Henry G. Gale and Albert P. Mathews, University of Chicago.

3. *The Fungi which cause Plant Disease;* by F. L. Stevens. 8vo, pp. 754, 449 figures. (The Macmillan Company, New York, 1913.)—The title of this work might naturally convey the impression of a popular general treatise on pathogenic fungi, perhaps after the order of H. Marshall Ward's book, "Disease in Plants." Although, of course, such books have their peculiar value, the present work is, as a matter of fact, not at all of this type. Dr.

Stevens' earlier book, "Diseases of Economic Plants," lays especial emphasis on the host in its treatment of the various diseases, dealing with the symptoms of the disease, prevalence, damage caused, methods of control, etc.; the present work is more or less complementary to this, in that it treats especially of the causal organisms.

After a brief introduction, the first part is devoted to the Myxomycetes and Bacteria, and Phycomycetes, Ascomycetes, Basidiomycetes and Fungi Imperfecti follow on in the order named. All genera and species of economic importance in this country, and a few so far known only in Europe, are included. Each genus of pathological importance is represented by at least one figure. Practical keys for the various groups of fungi are supplied throughout the book.

One of the most commendable points is the comprehensive bibliography appended after each part. Such references to the literature are particularly helpful to the student engaged in research, and as one looks through the book, the large number of fungi which are said to be "probably," or "perhaps" parasitic, or of which little seems to be known save the bare fact of their occurrence on a given host, is certainly convincing as to the great need of such research.

In addition to the bibliographies, lists of the more useful general works and periodicals, and a glossary and index are added. A few typographical errors appear here and there, and also some inconsistencies in the headings and bibliographical references; yet the book represents such a vast amount of labor and is so exceedingly valuable to students of plant pathology that we are loath to mention these imperfections at all. A. H. G.

4. *Measures of Proper Motion Stars made with the 40-inch Refractor of the Yerkes Observatory in the Years 1907 to 1912;* by S. W. Burnham. (Carnegie Institution of Washington, Publication 168.)—As one examines this record of a great contribution to an important branch of astronomical research, it is natural to contrast it with the earliest work of the same observer, done without any previous training with the simplest instruments in such fragments of time as could be saved from the business of a reporter for the courts of Chicago, but stamped, then as now, with the mark of an unequaled ability for observations of this kind. It need hardly be said that with the best telescope in the world, the best atmospheric conditions, and all the appliances of a great observatory at command, Mr. Burnham's work cannot be rivalled elsewhere.

The present volume, No. II, records about 9500 measurements, following vol. I, which covered the period from 1897 to 1906, published in the general Catalogue of Double Stars of the Carnegie Institution. The greater number of stars given in this volume are taken from the same volume. Stars of appreciable proper motion being in general our nearest group of neighbors, astronomically speaking, as well as fairly bright for the same cause,

the reason for selecting such double stars for measurement before exploring the field further is evident. "For many years," the author remarks, "I have been hunting for a faint star with some certain proper motion, but so far without success."

Considerable attention has been given to an interesting group of 39 bright stars, principally in Taurus, first noted by Boss, which appear to have a proper motion in common of about 0·10″ in the same direction. Mr. Burnham has added three more, and most of the 42 have been located by position angle and distance from one or more neighboring faint stars. W. B.

5. *Astronomy: A Popular Handbook;* by HAROLD JACOBY, Rutherford Professor of Astronomy in Columbia University. Pp. 435. New York, 1913 (The Macmillan Co.).—The accumulation of new material in astronomy warrants the publication of popular handbooks at short intervals, and this work brings the record up to date most satisfactorily, both in the choice of material and the form of presentation. If the ordinary reader cannot digest all that it offers, it is due to the subject rather than the author whose faculty both for elucidating and condensing is unusual, as is his independence of thought.

An example of the latter is his treatment of the question of the Martian Canals, a subject on which the public possesses a large amount of misinformation. Dr. Jacoby dissents from the theories of Percival Lowell whom he thinks to be the author rather than the discoverer of most of these canals, and those who wish to know the argument for the negative should not fail to read this book.

Many points of interest are excluded from this notice for want of space, but something should be said of the plan of the author to make the book serve the double purpose of a popular treatise and a satisfactory text-book for high schools and colleges. This he aims to do by keeping the text for 360 pages free from formal mathematics, condensing this into an appendix of 60 pages. The attempt does not seem to the present writer likely to succeed without much hard labor on the part of the teacher; except for the author, whose method is no doubt best suited to his own class room. W. B.

6. *The American Chemical Journal.*—The fiftieth volume of the American Chemical Journal, completed in 1913, closes the independent career of this important periodical. Started in 1879 at the Johns Hopkins University under the editorship of Professor Remsen, it has occupied from the start a prominent place in chemical literature and has done a great work in stimulating the ever-increasing activity of chemical research in this country. In future the papers, which would have come to it, will be cared for by the Journal of the American Chemical Society. An index to the fifty volumes of the American Chemical Journal is to be issued and will be sent, to those ordering it, by the Johns Hopkins Press, Baltimore; price one dollar and fifty cents.

Obituary.

Dr. Silas Weir Mitchell, gifted alike as investigator, physician, novelist, and poet, died on January 4 in his eighty-fifth year. Few men of any nation or time have been able to accomplish so rare a work in physiology and medicine and at the same time to take a place in the first rank of men of letters. His interests were as varied as his vigor was unlimited, and his activity continued till near the close of his long life. He will be mourned alike by a circle of friends as broad as the nation and by a host of grateful patients whom he helped to overcome their nervous ailments.

Dr. Benjamin Osgood Peirce, Hollis professor of mathematics and natural philosophy in Harvard University, died on January 14 in his sixtieth year. He was born on Feb. 11, 1854, and educated at Harvard, Leipzig, and Berlin. His original scientific work was varied and important, extending over both mathematics and physics; the phenomena of magnetism were of particular interest to him.

Dr. Seth Carlo Chandler, the distinguished astronomer, died at his home in Wellesley, Mass., on Dec. 31, at the age of sixty-seven years.

Professor Winslow Upton, head of the astronomical department of Brown University, Providence, died on January 8, aged sixty-one years.

Dr. Charles Budd Robinson, economic botanist of the Bureau of Science of the Philippine Islands, recently met his death at the hands of the natives of the Amboyna Islands; he was in his forty-third year.

Sir Robert Stawell Ball, the eminent astronomer, died in London on November 25, at the age of seventy-three years. Born in Dublin in 1840, he was professor of astronomy in the University of Dublin and Astronomer Royal of Ireland from 1874 to 1892. Later he became Lowndean professor of astronomy and geometry at Cambridge University and director of the Cambridge Observatory. He was knighted in 1886.

Sir Trevor Lawrence, the English botanist and president of the Royal Horticultural Society, died on December 22, 1913, in the eighty-second year of his age.

Dr. Penry Vaughan Bevan, the English physicist, professor in the Royal Holloway College, died on December 15, 1913, at the early age of thirty-eight years.

Dr. W. Popplewell Bloxam, formerly professor of chemistry at Madras, died on December 26, at the age of fifty-three years.

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CONTENTS.

Page

ART. VIII.—Geologic Reconnaissance of the Ayusbamba (Peru) Fossil Beds; by H. E. GREGORY 125

IX.—Vertebrate Fossils from Ayusbamba, Peru; by G. F. EATON. (With Plates V, VI, VII) 141

X.—The "Dam" at Cheshire, Connecticut; by F. WARD .. 155

XI.—Progressive Development of Mechanics based upon a New Form of Fundamental Principle of the Science; by H. M. DADOURIAN 157

XII.—Temiskamite, a new nickel arsenide from Ontario; by T. L. WALKER 170

XIII.—Use of the Ammonium Salt of Nitrosophenylhydroxylamine ("Cupferron") in the Quantitative Separation of Titanium from Iron; by W. M. THORNTON, JR. 173

XIV.—Contribution to the Optical Study of the Amphiboles; by W. E. FORD 179

SCIENTIFIC INTELLIGENCE.

Chemistry and Physics—Action of Aluminium Carbide upon Solutions of Metallic Salts, HILPERT and DITMAR, 193.—Solubilities at the Critical Temperatures of Solvents, F. FRIEDRICHS: Organic Chemistry for Advanced Students, J. B. COHEN: Industrial Chemistry for Engineering Students, H. K. BENSON, 194.—Outlines of Theoretical Chemistry, F. H. GETMAN: Oxygen in the Sun, RUNGE and PASCHEN, 195.—Fluorescence of the Vapors of Sulphur, Selenium and Tellurium, W. STEUBING, 196.—The Series Lines of Neon, R. ROSSI, 197.—Mass of Rapidly Moving Electrons, G. NEUMANN, 198.

Geology and Mineralogy—Changes in Level in the Earth's Crust, O. FISHER, 199.—Meteorites vs. The Earth, O. C. FARRINGTON, 200.—San Franciscan Volcanic Field, 202.—Devonian of Maryland: Stratigraphy and Paleontology of the Alexandrian Series in Illinois and Missouri, Part I, T. E. SAVAGE: Important part played by calcareous Algæ at certain geological horizons, E. J. GARWOOD, 203.—Geological Survey of Oklahoma: Minéralogie de la France et de ses Colonies, A. LACROIX: Handbuch der Mineralogie, C. HINTZE, 204.

Miscellaneous Scientific Intelligence—Semi-Centennial Anniversary of the National Academy of Sciences, 1863-1913, 204.—Annual Tables of Constants and Numerical Data, etc.: Fungi which cause Plant disease, F. L. STEVENS, 205.—Measures of Proper Motion Stars, S. W. BURNHAM, 206.—Astronomy, H. JACOBY: The American Chemical Journal, 207.

Obituary—S. W. MITCHELL: B. O. PEIRCE: S. C. CHANDLER: W. UPTON: C. B. ROBINSON: R. S. BALL: T. LAWRENCE: P. V. BEVAN: W. P. BLOXAM, 208.

Smithsonian Institution. (U. S. Nat. Mus.)

VOL. XXXVII. MARCH, 1914.

Established by BENJAMIN SILLIMAN in 1818.

THE AMERICAN JOURNAL OF SCIENCE.

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FOURTH SERIES

VOL. XXXVII—[WHOLE NUMBER, CLXXXVII].

No. 219—MARCH, 1914.

WITH PLATE VIII.

NEW HAVEN, CONNECTICUT.

1914.

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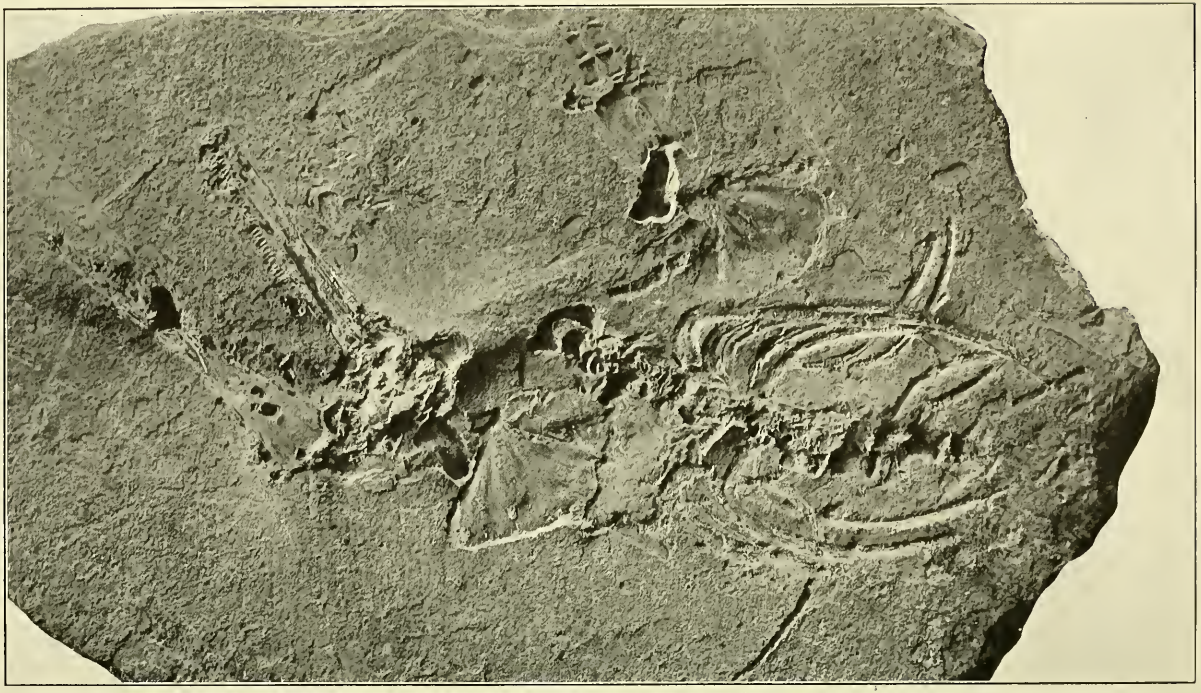


Photograph of entire fossil. 1/6 nat. size. Viewed from above, showing the left aspect of the skull and jaws, with the right paddle pointing toward the upper edge.

THE

AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

Art. XV.—*Fossil Dolphin from California;* by Richard Swann Lull. With Plate VIII.

[Contributions from the Paleontological Laboratory, Peabody Museum, Yale University, New Haven, Conn., U. S. A.]

Introduction.
Extent and preservation of the specimen.
Dedication of the specimen.
Morphology.
The axial skeleton.
Skull.
Jaw.
Dentition.
Vertebral column.
Ribs.
Sternum.
The appendicular skeleton.
Scapula.
Humerus.
Forearm.
Hand.
Summary.

Smithsonian Institution
MAR 2 1914
National Museum

Introduction.

There has recently been presented to the Peabody Museum at Yale University a slab of sandstone containing the impression of a small fossil whale, apparently one of the Delphinidæ, but otherwise new to science. It was found by Mr. Edwin White Newhall, Jr., of the Newhall Land and Farming Company, San Francisco, and presented by him to the Peabody Museum through the intermediation of the writer. In view of the scarcity of cetacean remains from the Tertiary rocks of the Pacific coast, and of the perfection of the relic, the specimen is eminently worthy of consideration.

The slab was found on the Suey ranch, owned by the Newhall Land and Farming Company, in San Louis Obispo county, California, in what is called "Sulphur Creek" canyon, about 700 feet above sea-level and 30 miles in a direct line from the ocean. According to the company's maps, the place is in the southeast corner of Section 17, Range 32, West Township 11, north San Bernardino Base and Meridian. Sulphur creek empties into the Santa Maria river at about the southern extremities of Sections 16 and 17, and Mr. Newhall found the specimen about a quarter of a mile up the creek.

The fossil is presumed to be of Miocene age, judging from the Geologic Map of North America published in 1911. The precise level, however, has not been determined, but is at present under investigation through the courtesy of Professor John C. Merriam, of the University of California.

Extent and preservation of the specimen.

The specimen, which bears the catalogue number 10040, Yale Museum fossil vertebrate collection, consists of a single slab of sandstone, upon the surface of which the articulated skeleton of the dolphin was impressed (see Plate VIII). Most of the bones have been eroded away, so that their imprints alone remain, with but little of the osseous material clinging to their depths. Of the skull, however, a great deal was preserved, for, while the exposed surface had suffered from weathering, removal of the matrix from the reverse side displayed most of the right aspect of the cranium and jaws.

There remains of the animal, therefore, the entire skull and jaws with many of the teeth, some entire, some having but the root embedded in the alveolus, and others represented only by their imprint in the matrix. The vertebral column is indicated as far as the twelfth dorsal, though each bone cannot be clearly distinguished. There are twelve pairs of ribs and the impression of the sternum is distinct. Of the limbs, the left scapula, the humerus, and the ulna are represented, and at least four phalanges of the second or third digit, while of the right paddle, impressions of all the elements remain except the distal ends of the several digits. There is unfortunately no trace of lumbar or caudal vertebræ, nor have I recognized any portion of the pelvis, which would be of great interest in so old a form. I should judge the animal to be fully adult despite its rather small size, as the bones show scarcely a trace of the epiphyses.

The only preparation for study necessary was the removal of the matrix from the right aspect of the skull, and, after a careful preliminary examination, it was deemed expedient to

eliminate the bone fragments clinging to the depths of certain of the impressions, especially those of the cervical series and of the right paddle, in order to secure by means of casts and otherwise the more exact contour of the bones themselves. One should fully realize that while the imprints are often deep, certain outlines become very vague and the extent of the various processes very difficult to determine.

The entire specimen is in a sense comparable to the deeply incised but partially effaced inscriptions on an Egyptian obelisk, and the interpretation of such an ancient hieroglyph is necessarily halting.

Dedication.

I propose for this form the name *Delphinavus newhalli*, n. gen., n. sp., the generic distinctions in contrast with *Delphinus* being outlined below. The species is dedicated to the family of Newhall, twice a contributor to the Yale collections, first through the late Henry G. Newhall of the class of 1874, Sheffield Scientific School, who accompanied Professor Marsh upon the Yale Expedition of 1873, and again through his nephew, Edwin White Newhall, Jr., Massachusetts Agricultural College 1906, the discoverer and giver of this important specimen.

Morphology.

For the purpose of comparison, I have, through the courtesy of Doctor George F. Eaton, used a mounted skeleton of *Delphinus delphis*, catalogue number 265, Peabody Museum osteological collection. This specimen is not quite mature, as the vertebral epiphyses are still free from their respective centra. The skeleton measures 5 feet 10 inches from tip of rostrum to that of the caudal series. The fossil, which as I have said, seems to have been fully grown, would have an estimated length of perhaps 5 feet, though the proportions of the various regions which serve to make up the total length differ in the two forms, as I shall show.

The Axial Skeleton.

Skull.—In the proportions of cranium to rostrum the form under consideration agrees most nearly with the modern dolphin, *Delphinus*, in contrast with those proportions seen in *Phocæna*. The most apparent cranial contrast with *Delphinus* is the higher, more nearly vertical occiput which in the fossil makes a sharp angle with the roof of the skull at the vertex, instead of rounding forward as in the modern form. The precise limits of the various bones are not to be determined with assurance in many cases, but they agree in general with those

of *Delphinus*, with the following exceptions. The exoccipital bones in the fossil have a much less lateral extent in proportion to their height. The squamosal bone is very robust and broadly expanded antero-posteriorly so as to be both actually and relatively larger and heavier. The orbit is large and well rounded and the superior limiting bones, frontal and jugal, are compar-

Fig. 1.

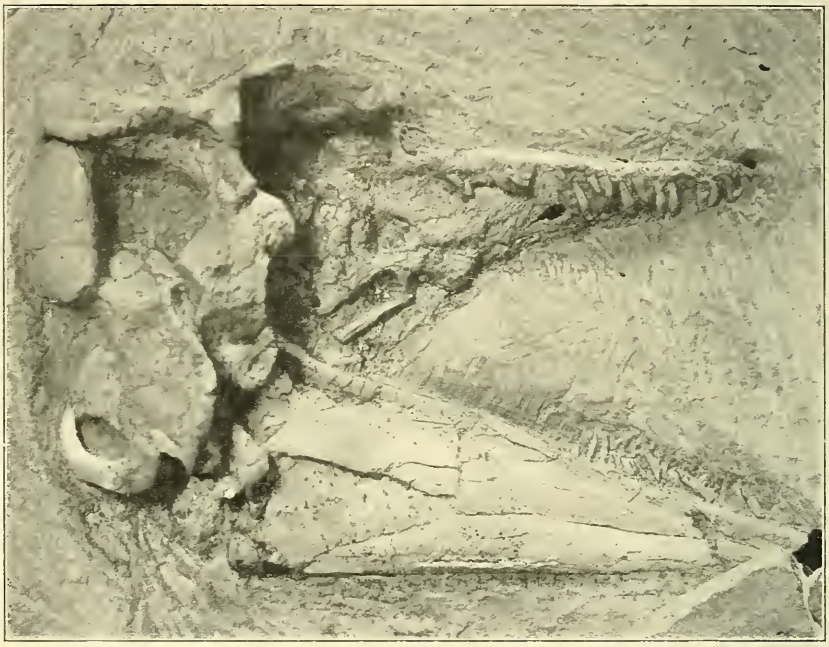


Fig. 1. Skull seen from the right, about ½ nat. size.

atively heavy. The frontal plate of the maxilla does not appear to have the full lateral or posterior expanse which is characteristic of the modern type, as its presence cannot be detected in the antorbital or orbital regions viewed laterally. What appear to be fragments of the zygomatic process of the jugal are at least twice the diameter of that of *Delphinus*. In the sharp-edged posterior limitation of the temporal fossa, the fossil agrees with *Delphinus* in contrast to *Phocæna*.

Jaw.—The two forms may be contrasted in the proportions of this bone, for whereas the entire length of the mandible is 278^{mm} in the fossil to 370^{mm} in the recent form, their vertical expanse at the posterior end is essentially the same. This

coupled with a more robust angle in the fossil implies a greater proportionate jaw power in the older form. In the latter the symphysis is apparently longer, though the distal two-thirds of each jaw is about equal in slenderness.

Dentition.—The dental formula of *Delphinus* is $\frac{40}{42}$. In the fossil the number of teeth in the upper jaw is exactly the same,

Fig. 2.

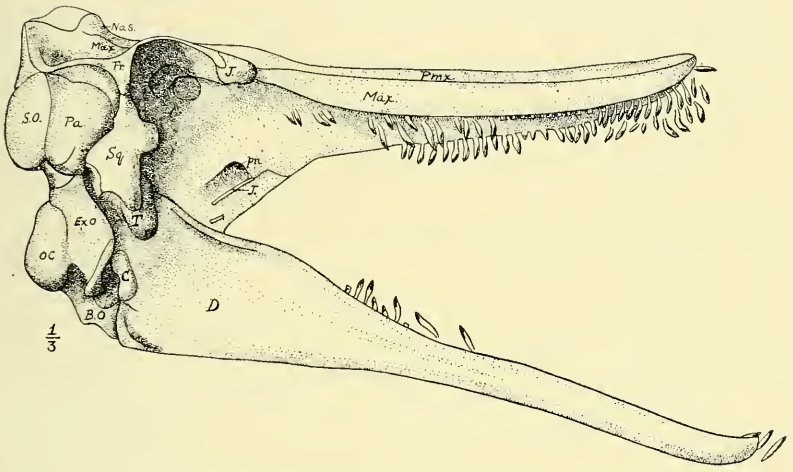


Fig. 2. Right lateral aspect of skull and jaws. $\frac{1}{3}$ nat. size. *Bo*, basioccipital; *C*, condyle of jaw; *D*, dentary; *Exo*, exoccipital; *Fr*, frontal; *J*, jugal; *Max*, maxillary; *Nas*, nasal; *Oc*, occipital condyle; *Pa*, parietal; *Pmx*, premaxillary; *Pn*, ?posterior nares; *Sq*, squamosal; *So*, supraoccipital.

but the imperfection of the mandible renders a count of the lower dentition impossible. There is no reason, however, to suppose that the number here was not also essentially similar. In each instance the premaxillary bone is toothless.

The teeth themselves are also alike, being simple, slightly recurved cones without carinæ, and with smooth, polished enamel. They contrast sharply with the spatulate crowned teeth of *Phocæna*.

In so far as I am able to judge, the skull and dentition of the fossil agree essentially with those of *Delphinus*, the exceptions being all in the direction of greater cetacean specialization on the part of the latter, such as the character of the occiput, the reduction of the zygomatic arch, and the lessened jaw power.

Measurements of the skull.

	Delphinavus Cat. No. 10040	*Delphinus* Cat. No. 265
Length, including rostrum	290mm	440mm
" anterior end of jugal to tip of rostrum	181	265
Height, vertex to lower margin of exoccipitals	117	150
Antero-posterior diameter of orbit	35	49
Length of mandible	278	370
Height of mandible at posterior end	64	66·5
Space for 10 alveoli in rear of maxillary	43	47
Maximum length of crown of tooth	06	08
Squamosal, height	40	41·5
" exposed breadth	36	21
Tympanic bone, greatest diameter	30	---
Height of mandible at mid-length	17·5	26·5
Length of symphysis	32·4	37
Vertical diameter of mandibular condyle	20·5	23

Vertebral column.—Cervical vertebræ. The cervicals are recorded only as deep impressions in the matrix, so that their

Fig. 3.

Fig. 3. Impressions of cervical vertebræ. ½ nat. size. *I*, atlas; *fac*, posterior facet of atlas; *z*, postzygapophysis of axis; *dI*, ? first dorsal; *VII*, seventh cervical.

interpretation is accompanied with great difficulty and the apparent results may not be in harmony with the actual facts. The vertebræ seem to be entirely free, the atlas presenting its posterior aspect, with well-developed, slightly convex facets for articulation with the axis, such as *Delphinus* might well exhibit were the bones not coalesced in their lower half. The right diapophysis is indicated. The axis seems to have been a rather

massive bone, and exhibits again the posterior face of the centrum, which is concave with well-rounded margins. The axial arch and spine, the former exhibiting a well-developed postzygapophysis upon the left side, are well preserved but apparently entirely detached from the centrum.

I can discern with fair assurance the impressions of five or six cervicals in proper sequence, but what is apparently the sixth shows a diapophysis comparable in development to that of the seventh in *Delphinus*, while just beyond it there lies an impression very suggestive of the diapophysis which in the modern form articulates with the tuberculum of the first rib; one cervical is therefore either missing or too obscurely defined to be recognized.

In comparison, then, with *Delphinus*, the fossil again exhibits more generalized traits in the free cervicals, in their actually greater length in the smaller specimen, and their much greater relative size. They seem to represent more nearly the degree of evolution shown by *Inia*, but display no feature which would debar the older type from direct ancestry to *Delphinus*.

Measurements of the cervical series.

	Delphinavus Cat. No. 10040	*Delphinus* Cat. No. 265
Length of entire series	74mm*	47mm
Width of atlas	62·5	119
Height of axial spine measured from base of postzygapophysis	46	40

Dorsal vertebræ.—At least twelve rib-bearing vertebræ are preserved, comparable in number to those of *Phocæna*, and three fewer than in *Delphinus delphis*. However, this is of little moment, as the remainder of the body is lacking in the fossil so that the number of dorsals and ribs may readily have been greater.

The vertebræ differ markedly from those of either of the above mentioned genera in the much greater length of centrum and in the low neurapophysis in contrast with the very high spine of an approximately equivalent vertebra of the recent form. The proportions of the vertebral centra are more nearly those of *Inia* again, though in that genus the neutral spine is much higher.

FIG. 4.

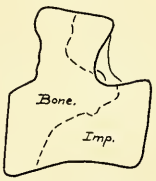


FIG. 4. ? Ninth dorsal vertebra, left aspect. ½ nat. size. *Imp.*, impression.

* This is not a just measurement, for the vertebræ are slightly displaced.

Measurements of dorsal ? IX.

	Delphinavus Cat. No. 10040	*Delphinus* Cat. No. 265
Length of centrum	38 mm	23 mm
Height of centrum, posterior end	21·8	29·5
Total height, including neural spine	44·1	110

Ribs.—Twelve pairs of ribs are preserved in the specimen, of which at least four pairs were double-headed, in comparison

Fig. 5. Fig. 6.

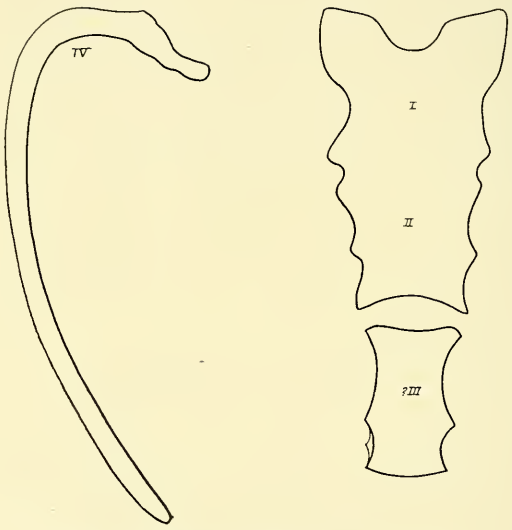


Fig. 5. Fourth rib. ⅓ nat. size.
Fig. 6. Sternal impressions. ⅓ nat. size.

with five in *Didelphis* and six in *Phocæna*. It seems hardly possible that in this regard the ancient type is more specialized than *Delphinus*, while in every other respect in which they do not agree the reverse is true. The ribs are quite comparable to those of *Delphinus* in proportions and general curvature.

Measurements of the ribs.

	Delphinavus Cat. No. 10040	*Delphinus* Cat. No. 265
Length of first rib, measured along the chord	99mm	120mm
Length of fourth rib	200	225

The torso of the fossil form was evidently fully as long and deep as that of the dolphin used for comparison, though the skull of the latter is materially larger.

Sternum.—There are two impressions not far removed from their normal position which I take to be those of two coalesced and one isolated sternebræ. The outlines are very vague in each instance but the anterior one seems to differ very markedly from that of *Delphinus* and to resemble more nearly that

FIG. 7.

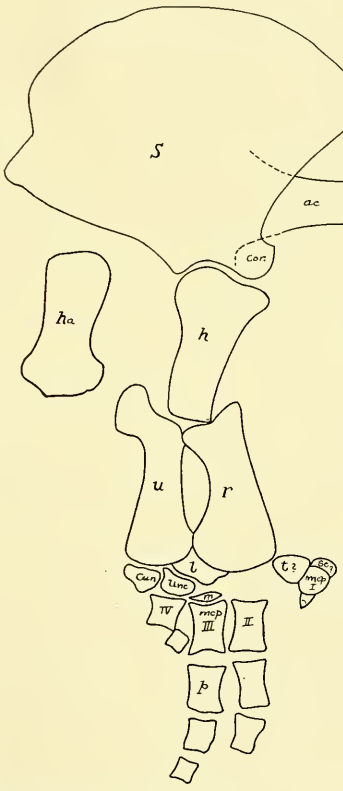


FIG. 7. Right pectoral limb. 1/3 nat. size. *ac*, acromion process; *cor*, coracoid process; *cun*, cuneiform; *h*, humerus, anterior aspect; *ha*, humerus, internal aspect; *l*, lunar; *m*, magnum; *mcp*, metacarpal; *p*, phalanx; *r*, radius; *s*, scapula; *sc?*, ?scaphoid; *t?*, ?trapezoid; *u*, ulna; *unc*, unciform. Drawn from the impression.

of *Platanista*. The difference is mainly in the greater size of the element in the fossil and in its simplicity of outline. The anterior margin has a simple semicircular notch about one-third the width of the entire bone, whereas in *Delphinus* the notch

has become converted into a foramen through the closing together of the anterior margins. In *Delphinus* the lateral edges of the anterior sternal are prolonged into ontward and backward projecting cornua, while in the other there are simple rounded angles in their place and the width of the sternal posterior to them is relatively much greater.

Measurements of the sternum.

	Delphinavus Cat. No. 10040	*Delphinus* Cat. No. 265
Length of sternals 1 and 2	120mm	124mm
Greatest breadth	70	84

I cannot positively identify sternal ribs in the fossil.

The Appendicular Skeleton.

Both paddles are preserved, that of the right side almost entire, the left more or less occluded by the skull but supplying certain details lacking in the other due to the orientation of certain of the bones, notably the humerus.

The limb is essentially delphinoid, showing apparently the same reduction of digits, but differing mainly in the more primitive character of the individual elements. In so far as it is preserved, the limb is of approximately the same size in both modern and fossil forms.

Scapula.—The scapula is less widely expanded than that of *Delphinus*, otherwise the two are very suggestive of one another. In the fossil the horizontal extent of both coracoid and acromion processes cannot be ascertained; they are, however, similar in the extent of their origin to those of *Delphinus*. The prescapular fossa seems to have been relatively greater in the ancient type.

Humerus.—The ratio of humerus to radius is much greater in the fossil, as one would be led to infer in the case of the more primitive form. The humerus is also relatively more slender, but has much the same general outline as in *Delphinus*, except that the tuberosity projects slightly above the head and has a lesser transverse extent. A faint indication of the capitular epiphysis may be seen in the fossil, practically the only indication of one in the entire skeleton. The right humerus presents the impression of its posterior aspect, while the left is viewed from without. The latter shows the character of the distal facets, each of which is planoconcave, the curved axis lying in the transverse plane. The radial facet is the greater, as in *Delphinus*.

Forearm.—The forearm presents perhaps the greatest divergence in the two forms of any part of the limb, for instead of

being nearly parallel as in *Delphinus*, the two bones are separated by a wide lenticular space, the curved line of the radius being particularly noticeable. In the ulna the olecranon is better developed but simple in outline.

Hand.—The carpus is essentially alike in both genera, but here again the fossil is the more primitive in that the magnum is represented by a well-defined lenticular bone lying at the proximal end of metacarpal III; whereas in the specimen of *Delphinus* used for comparison, it is reduced to a tiny nodule closely adpressed against the unciform and visible only from the inner aspect of the wrist. Its position, however, is exactly the same in each form. In the fossil the bones of the anterior side of the carpus have been displaced, but their identity seems fairly certain.

The metacarpals show much the same proportions in each genus, but the preserved phalanges are relatively longer and more slender in the fossil, no separate phalangeal epiphyses being discernible. The digital reduction has gone further in the modern type, as evidenced by the proximal phalanx of digit IV, which is a much better developed bone in the fossil.

Measurements of the pectoral limb.

	Delphinavus Cat. No. 10040	*Delphinus* Cat. No. 265
Scapula, height	105mm	104mm
" breadth	146	160
Humerus, length	60	60
" proximal breadth	37	49
" ant.-post. diameter, distal end	31·5	38·5
" transverse " mid shaft	19·5	24
Radius, length	67·3	84
" diameter, proximal end	25	28·5
" " distal end	33	37·5
Ulna, length	71·5	72
" diameter, proximal end	26·5	30
" " distal end	26	27
Metacarpal III, length	20	32
" " breadth of shaft	11	14
Digit III, 1st phalanx, length	19·5*	21·5†
" " 2d " "	11·5	17
" " 3d " "	08	13
Length of digit, inc. metacarpals, estimated	80	100
" " entire limb, inc. scapula, "	320	360

Summary.

The specimen under consideration is clearly a dolphin allied to *Delphinus* and hence of the family Delphinidæ. It com-

* No epiphyses nor articular cartilages indicated, but bones are spaced.
† Including epiphyses, bones in contact.

pares favorably with the dolphins of this genus in point of size, proportion of rostrum to cranium, in dental formula, character of the dentition, in having approximately the same number of double-headed ribs, and in the general character of the pectoral limb, more especially of the manus.

The contrasts are in practically every instance due to the more primitive character of the fossil, and I fail to recognize one which would debar the more ancient type from a direct ancestry to *Delphinus delphis* itself. To sum up these contrasts, they are: In the skull, the straighter, more nearly vertical occiput, the minor proportions of the individual cranial elements, the more robust zygomatic arch, the less expanded maxillary plate, and the more broadly expanded and powerful rear portion of the lower jaw. The cervical vertebræ, in so far as may be learned, differ mainly in the lack of fusion of atlas and axis in the fossil and the somewhat greater collective length of the entire series. The dorsals are much longer in centrum and lower in the height of the neural spine, while the number of double-headed ribs in the two specimens is apparently four for the fossil and five for the recent type, the only instance wherein the former seems to be more specialized, and this may be due to lack of perfection of the fossil.

The sternum of the older form is simpler and more generalized, but easily modified into the modern type. In the limbs, the contrasts lie in the less widely expanded scapula, relatively longer humerus, wide lenticular space separating the radius and ulna, and in the simpler form of the olecranon in the fossil. In the carpus the magnum is relatively large, while in the recent type it is vestigial. The phalanges are relatively longer in the ancient type.

The degree of evolution of the two dolphins is doubly interesting when compared with the advance manifest in the same length of time in certain terrestrial families, notably the horses. It points to the early adaptation of the Cetacea to their aquatic habitat and their slow subsequent evolution, which amounts, in this instance, merely to the adjustment of certain minor details, some, as in the jaw power, along the line of degeneracy, others mainly for the perfection of speed.

This evolution shows the impelling force of topographical changes on the land, which not only directly modify the animal form and motor organs, but also, through influencing climate and thereby vegetative life, necessitate new adaptations on the part of terrestrial animals or the elimination of those forms which cannot thus change. All of this passes harmlessly over the head of the cetacean, which can migrate when the waters become too cold, and upon which none of the other influences can make themselves felt.

ART. XVI.—*Note on the Occurrence of the Oriskany Formation on Parlin Stream, Maine;* by L. V. PIRSSON and CHARLES SCHUCHERT.

THE material which is the subject of this communication was collected by one of the writers (L. V. P.) while traversing this portion of Maine with his guide, and as Oriskany fossils occur here it has seemed worth while to put this on record and give a list of the species obtained, together with a mention of the exact locality and some additional observations which may be of future service in the study of the geology of this part of the state.

Parlin Stream is the outlet of Lake Parlin, which lies 20 miles southwest of Moosehead Lake, where Oriskany fossils have long been known to occur.

While the mere crossing of a country which is so heavily forested, as is this portion of Maine, affords little opportunity to gain much idea of its geology, the following facts were observed, in relation to this occurrence.

The fossils were found in loose, angular blocks of a much indurated shale or shaly sandstone of a dark green to brown color, weathering with a blackish chocolate-brown crust. They are seen on exposed bedding planes of the firmer material or in more weathered, cavernous, sandy fragments and they constitute a great part of the rock mass, like the so-called shell limestones of other places. These blocks occur on the west side of the large pool immediately below the partly burned lumbering dam, about a quarter of a mile above the falls on Parlin Stream. The locality is about two and a half miles from the outlet of Parlin Lake. This same locality was collected from by Gilbert van Ingen in 1889 (Bull. U. S. Geol. Surv. 165, 1900, p. 89).

The country in this locality is composed of heavily bedded, much indurated, or metamorphosed, strata which have been upturned. At Parlin Falls there is a good exposure of the beds. The falls are made by the stream passing downward over the inclined back of a heavy resistant bed. At this point the strata have a general east and west strike and dip northward at a considerable angle, perhaps 45°. Below the falls the stream has cut a very respectable canyon, whose exposures should afford a good opportunity for study of the formation. All the exposures weather with the blackish crust mentioned above.

While the material containing the fossils was not observed in place, it is quite certain from considerations of the local geology seen that it belongs in its immediate neighborhood,

and had suffered little transport. This is shown by the abundance of blocks, their large size, angular shapes, unworn condition and characteristic resemblance to the nearby rocks in place. It is presumed that they represent the debris of broken down beds of the immediate vicinity. The supposition that the blocks are local in origin is further supported by the rather noticeable absence in this neighborhood of the coarser material of glacial transport. Glacial sands and gravels containing pebbles or very small bowlders are common, and in morainal forms, as in drumlins, etc., are rather frequent topographic features, but the larger glacial erratics, which are so striking a feature of the region farther south, were not observed in the stream beds, on the lake shores, or in other places where erosion might have brought them to the surface.

Toward the lower end of Lake Parlin there is a large intrusive mass of trap rock. It is exposed in outcrops on the road; large bowlders of it are seen along the lake shore, and massive outcrops at several places. It rises into Parlin Mountain, where, as it was found at the north end and on the trail to Long Pond as it winds about the mountain, it is inferred that it forms the main upper portion of this eminence. No contacts were seen and its intrusive nature is inferred from the size and position of the mass, the nature of its jointing, and the petrographic characters of the rock. On a fresh surface of fracture it is a dark gray to green and of uniform and fine texture. Examination in thin section shows that it is a greatly altered diabase. Originally it consisted of plagioclase and a brownish augite with accessory iron ore and apatite, with occasional very fine, delicate micrographic intergrowths of quartz and orthoclase filling interstices between the plagioclases. The structure was the characteristic ophitic one, but the proportion of plagioclase to augite was large, making the rock one of feldspathic type.

From this condition the rock has been greatly altered; the augite has been changed into chloritic substance, which preserves the outlines of the ophitic fillings between the feldspars and contains in a few places still unaltered pieces of the unchanged augite. While this chloritic substance, for the most part, appears of the nature of ordinary green, pleochroic chlorite with low double refraction, it contains frequent minute bundles of radiant fibers of a more yellowish color and with rather high double refraction, which is suspected to be an iron-bearing serpentine. Some separated silica also is seen, but no formation of any carbonate was observed.

The feldspars are also altered and the original albite twinning so much obscured or obliterated that their character cannot be accurately determined, but they are thought to be

andesine-labradorite. They are also filled with infiltrated chloritic substance. The iron ore is changed to leucoxene and the apatite and micrographic intergrowths are the only unchanged constituents. The rock finally weathers with a brown crust of limonitic material. The mass is a large one and must be a prominent factor in the structure of the local geology.

The fossils collected by Mr. and Mrs. Pirsson on Parlin Stream are from the Moose River sandstone, one of the Oriskanian formations. The first good geologic account of this region dates back to 1861, when Charles H. Hitchcock determined the Oriskany sandstone here. In 1889, Van Ingen collected fossils along Parlin Stream for H. S. Williams, and in 1905 O. O. Nylander gathered other material for John M. Clarke. The latter has brought together all that is known about the Oriskanian of this area in his work, "Early Devonic History of New York and Eastern North America" (Mem. 9, N. Y. State Mus., 1909, pp. 52–90, pls. 12–21).

Below is given an annotated list of the Oriskanian fossils from Parlin Stream, just below the old dam above the falls, Somerset County, Maine, collected by Mr. and Mrs. Pirsson.

Brachiopoda.

Pholidops terminalis Hall. Two specimens.

Dalmanella drevermanni Clarke ? Two small specimens.

Chonostrophia dawsoni (Billings). One large and two young specimens.

Leptocœlia flabellites (Conrad). Common.

Spirifer pirssonæ, n. sp.

Clarke did not name this form, but has it from Telos Lake dam, and Moosehead Lake, 7 miles north of Kineo. He states that the form is common and that he thinks it "will prove unlike any known to us." The interior resembles very much the common Oriskanian guide species, *S. murchisoni*, but as all of the specimens are mature, never attain to one-half the size of *S. murchisoni*, and have a smaller number of plications, it is here proposed to name the new form *S. pirssonæ*, after Mrs. Pirsson, who collected and presented to the Peabody Museum of Yale University an abundance of natural moulds. Further, the six plications on each side of the fold and sinus never attain the prominence or angularity of those in *S. murchisoni*. The species is based on the cotypes figured by Clarke in the work cited on Plate 20, Figures 9–12.

Spirifer, n. sp.

This common species gives the impression of being

closely related to *S. pirssonæ*, but although both are fimbriate Spirifers, they are clearly of different stocks. The two forms are not associated in the same layers. The species under discussion is more quadrate than the foregoing one, has a narrower ventral cardinal area, and therefore is also less thick shelled and less rostrate in these parts. It differs chiefly, however, from *S. pirssonæ* in having a wider and more flabellate ventral muscle field. As the material is hardly good enough to figure, the form is left unnamed for the present.

Meristella lata (Hall)? A single much squeezed example.
Rensselæria callida Clarke. Rare, and much smaller than the original material.

GASTROPODA.

Plectonotus derbyi Clarke. One specimen.
Tropidodiscus obex Clarke. One specimen.

Yale University, New Haven, Conn., Dec. 1913.

Art. XVII.—*The Upper Devonian Delta of the Appalachian Geosyncline;** by Joseph Barrell.

Part III. The Relations of the Delta to Appalachia.

Introduction and summary 225
Indications given by the strata of former extension 226
Faunal relationships and the possible seaways 226
Character of the sediments of the marginal outcrops 229
Rate of thinning at the present margins 231
Evidence from the Green Pond Mountain region 234
Relations of piedmont gravels to climatic and crustal movements 239
Volume and sources of Upper Devonian sediment 243
Lack of relation of Appalachia to the continental shelf 247
The control by the continental shelf on paleogeographic maps 247
Breadth of Appalachia implied by the volume of sediments 248
The shelf a terrace of post-Paleozoic construction 249
The ocean basins widened by continental fragmentation 252
Conclusion on Appalachia in the later Paleozoic 252

Introduction and Summary.

The descriptions of the significant formations and the interpretations given in the first part upon the delta and its relations to the interior sea follow present well-known paths of geologic thought, but the search eastward and northward for the original boundaries involve interpretations which are much less customary,—interpretations in fact which are contrary to those which have prevailed. A preliminary consideration was therefore necessary in the second part on the factors controlling the present limits of the strata and the lack of relationship to the original boundaries. This has prepared the ground for the development of the conclusions, resting in part upon evidence, in part upon theory, as to approximately what those original limits were, as shown in fig. 1.† The subject leads up also to the relations of the delta to Appalachia and the information which is given thereby as to the character of that ancient land.

Briefly, the lines of argument are as follows: The marine fauna of the interior sea shows a connection eastward around Appalachia and implies a far extension, possibly to the south, but more probably to the north, of strata long since broadly uplifted and eroded. The character of the sediments and the rate of thinning at the present margins point to the same conclusion of a northward extension. The same lines of evidence

* Continued from this Journal (4), xxxvii, pp. 87 to 109, 1914.

† Published on p. 430, part I, Nov. 1913, and on p. 89, part II, Jan. 1914.

show that on the east not only did the strata once extend many tens of miles, but that the sources of erosion were not nearby. The evidence contained in the formations of the Green Pond Mountain outlier shows that the Upper Devonian deposits were there of fluviatile origin and of materials brought from a distance. The structure as well as the composition point to the present syncline being a mere fragment of the original deposit, downfolded and downfaulted, and thereby preserved from erosion. The Green Pond Mountain axis was consequently not an isolated bay but its sediments were originally a part of the general Paleozoic mantle thinning to the eastward and in that direction were commonly of coarser texture. In the Upper Devonian it was part of a broad piedmont gravel plain, a continental bajada of low grade skirting the mountains of Appalachia; a gently inclined and graded plain, sensitive to climatic and diastrophic changes.

Following this part on the character and original limits of the Upper Devonian sediments, is given a discussion of the volume and sources of the material. It is concluded that Appalachia was not confined to the limits of the present continental shelf. The shelf in fact is to be regarded as in considerable part an aggradational terrace built out in post-Jurassic time. The foundations of Appalachia are buried some thousands of feet beneath it, extend beyond it, and doubtless slope gradually for an unknown distance toward and beneath the basin of the Atlantic Ocean. In Upper Devonian times the mountains which rose above these foundations stood on the eastern side of the Appalachian system.

Indications Given by the Strata of Former Extension.

Faunal Relationships and the Possible Seaways.

According to Schuchert, the Upper Devonian faunas of the Appalachian geosyncline show a connection with the Atlantic province and in his Paleogeography he has located a strait across northern New Jersey as the channel of ingress.* The existence of an Upper Devonian seaway in this locality, however, seems impossible. In the first part was developed the evidence showing that the Upper Devonian of this region must be regarded as continental in origin. Furthermore the sediment appears to have come from lands in this direction. In the search for an available connection with the north Atlantic faunas we must look for a passage around either the southern or northern end of Appalachia. A southern route would not be a direct one for the migration of North Atlantic

* Bull. Geol. Soc. Am., xx, p. 545, pl. 77, 1910.

faunas. Eastern uplands supplying waste seem to have existed as far south as the latitude of Virginia and a more southwestern passage would have apparently made it easier for southern or interior faunas to invade southwestern New York. The postulation of a northeastern route, on the other hand, has the objection that Upper Devonian strata are unknown in the Upper St. Lawrence valley. Moreover, the Middle and Upper Devonian deposits which exist in Gaspé are all or nearly all of continental origin, except at the base of the Middle Devonian. This evidence or lack of evidence does not exclude, however, the possibility of the existence in the Upper Devonian of a shallow seaway over the Saint Lawrence valley or even farther northwest, mantling the margin of the Canadian Shield.

The Gaspé sandstone of Middle Devonian and early Upper Devonian age shows thick outcrops eroded toward the north. The crucial question here is whether the sediments came from the north or south. If from the north, then a Middle Devonian sea could not be supposed to have existed in that direction. If from the south, the Gaspé sandstone, like the Catskill of Pennsylvania, may have been a delta deposit built from the south and facing a shallow sea to the north. Above an unconformity, the Bonaventure formation, latest Devonian and earliest Mississippian in age, on the eastern shores of Gaspé, is regarded by John M. Clarke as a shore conglomerate. In view of the crustal disturbances which affected the Maritime Provinces in the Upper Devonian, such a sea seems as likely to have entered from the north, the region of little disturbance, as from the east or south, the region of orogenic and igneous activity.

The Devonian seas extended much farther, in some cases at least, than the remaining outcrops indicate. The agglomerates connected with the intrusions of the Monteregian Hills show on St. Helen's Island, opposite Montreal, fossiliferous masses of Helderbergian and Oriskanian limestones. The highest local rocks are Ordovician, and the nearest outcrops of these Devonian horizons are more than a hundred miles distant. The mixing of inclusions in the volcanic pipes has carried material some thousands of feet upward from the pre-Cambrian base and mixed it with other material carried several thousands of feet downward from formations now completely removed from the region.*

The accidental preservation of these fragments through such unusual means suggests how widely certain seas may

*Chas. Schuchert, Am. Geologist, xxvii, 245–253, 1901. H. S. Williams, Trans. Royal Soc. Canada, 3d Ser., iii, Sec. IV, 205–246, 1910. Robert Harvie, Trans. Royal Soc. Canada, 3d Ser., iii, Sec. IV, 249–299, 1910.

The evidence of this locality and its important bearing on the principles of paleogeography were called to the writer's attention by Professor J. A. Bancroft.

have extended beyond the present outcrops of their strata in cases where the strata do not show internal evidence of the proximity of a shore. On the other side of the argument, although several masses of Lower Devonian age have thus been preserved, none from the Upper Devonian has been found.

As similar testimony from another region, attention should be called to the observations by Weller regarding the accidental preservation of a late Upper Devonian fauna in a fissure in Silurian limestone near Chicago.* The nearest known Upper Devonian strata occur 80 miles north and 130 miles west, but even these beds appear to be somewhat older than the filling of the fissure. The nearest place where Devonian strata form the surface rock is probably under the heavy drift in northwestern Indiana.

The Laurentian province was not involved in the vigorous Upper Devonian mountain-making. Nor were these movements marked by a wide withdrawal of seas from the more quiet areas. Over such a region as that north of the St. Lawrence valley shallow ocean water may have spread consequently to a considerable distance. The strata, if they once existed, have not been preserved by infolding nor by the downfaulting which has protected remnants of some older Paleozoic formations within the Laurentian Plateau; but such facts as those cited show the possibility of the extension of shallow seas over lands not subjected at the time to uplift; and the later obliteration of the sedimentary evidence upon regional elevation followed by prolonged erosion.

Professor Schuchert has pointed out to the writer, however, that in the late Silurian the bay faunas of that time appear to have been distinct from each other in New York and in the Maritime Provinces. Of the latter region, however, but little is known. A more declaredly marine facies appears furthermore in the Great Valley Province of the Appalachians, suggesting that the sea lay in that direction, a strait opening either across New Jersey or farther south; but that no connection is probable through the Saint Lawrence Valley. He has called attention, however, to the Monroe problem of Grabau, the strata near Detroit holding a fauna seemingly unrelated to the other faunas of the period, and which may have entered from the north. Although Schuchert and the writer are agreed as to the general improbability of waterways crossing the trends of mountain structures in times of orogenic activity, there seems to be no incompatibility of their crossing after long periods of erosion, and due to broad warpings or local downsinking. Such relations are especially possible when they

*Jour. Geol., vii, 483–488, 1899.

antedate the chief period of mountain building. Successive periods of orogenic activity seem in general to extend and weld together axes of movement which were previously more or less separate. A mountain barrier in the Upper Devonian in this region is therefore not evidence against a transverse strait in the late Silurian provided the faunas of the latter period indicate its probability.

In regard to the Hamilton epoch of the Middle Devonian, an Atlantic passage should be looked for however rather to the south of New Jersey, or else along the northwestern side of the Saint Lawrence axis. It is seen that there is no positive evidence as to either connection; the southern seaway would be the shorter to the *present* ocean, but in the latter part of this paper the evidence is presented which suggests that Appalachia was of considerable breadth and the Devonian Atlantic was not so near. Furthermore in the Upper Devonian the sedimentary evidence is more positive that marine connections could not have existed north of Virginia, probably not north of North Carolina.

This problem of the relationships of the fauna of the Chemung sea and its connection with the Atlantic province is really not a vital part of the problem of the Upper Devonian delta and may be left in this indeterminate state. It has been dealt with so far as it is necessary to show that other connections could possibly have existed besides that which has been postulated as crossing New Jersey. The latter seems clearly disproved by the whole assemblage of evidence, and it is seen that an easier line of ingress may be conceived along the northwestern side of the Appalachian deltas.

Character of the Sediments of the Marginal Outcrops.

Where the edges of the upturned folds show strata many thousands of feet in thickness as in Pennsylvania, or where almost similar thicknesses of nearly horizontal beds remain in mountains of circumdenudation, as in the Catskills of New York, it is clear that in most cases the formations must have thinned out gradually beyond their present limits. The only exception is found on the borders of fault troughs. There a continual raising of the walls and a simultaneous settling of the basin permits a deep filling of debris at the very base of the block mountains. Such a condition records its evidence if the formations are of continental nature, by talus conglomerates and alluvial fans. If the fault movements are principally of profound subsidence rather than of uplift, as around the present-day shores of Greece, wave-formed conglomerates may be expected to mark the presence of the shores, passing outward rapidly into comparatively deep-sea deposits. In the formations

of the Upper Devonian of the Appalachian geosyncline, however, the sediments on the eastern outcrop are alluvial deposits of rather uniform nature. They are dominantly siliceous sandstones, argillaceous sandstones, some conglomerates of fine, well-worn gravel, and considerable shale. There is no sharp change near the present margin. The sediments therefore show no indication of an immediate source of erosion. If the size and abundance of pebbles in what there are reasons to believe were once continuous alluvial deposits be used as a means of estimating relative distances from the sources of erosion, it is to be noted that in the Skunnemunk outlier the coarsest pebbles of the conglomerate lie in the upper part of the formation. They are well water-worn, of quartzite, showing much previous transportation even here, and range from six to eight inches in maximum diameter. The average pebbles are about half this size. In the section of the Catskill rocks exposed from the town of Catskill to the summit of High Peak, 3660 feet elevation, it is the portion at 2000 feet and above to the mountain summit which shows notable conglomerate beds, the pebbles commonly ranging from 1·5 to 2·5 inches in diameter. The pebbles are largely quartzite. The southeastern outcrop in Schuylkill County, Pennsylvania, is more dominantly sandy, less conglomeratic. The pebbles there are of vein quartz and range from 0·5 to 1·5 inches in diameter. In the western outcrops conglomerates are very thin and fine-grained, or wanting. These observations are not along the same section and are incomplete, but they show something of the rate of disappearance of gravel at distances progressively greater from the source of supply. They suggest that even the easternmost outcrops are not close to that source.

The outlier known as the Rensselaer plateau deserves separate mention, although the age of the Rensselaer grit which constitutes it is not positively known and is more likely Middle rather than Upper Devonian. These sediments have been described in the first part of this article (p. 448), the metamorphism and the relations to the Taconic Range in the second part (p. 95). Although the sediments show by their character and variety that they are nearer to the sources of erosion than are those of the main area of the geosyncline, they do not show that the present limits of the Rensselaer formation hold any direct relation to the original boundary.

The previous statements have referred to the continental deposits of the eastern outcrops of the Upper Devonian. On the northern side of the basin the present limiting outcrops of both continental and marine nature show the principal relation in their sediments not to a nearby northern land but to sediments from the southeast and to Appalachia beyond. The

rocks are thin, even-bedded shales and sandstones traceable for long distances along their outcrops. They suggest for the greater part of the deposits the smooth floor of an open shallow sea. The dark mud-cracked shales of the Portage in central New York appear to be delta deposits developed because the subsidence was slower than the infilling, but the fine even grain of the sediments shows that even these are far from the sources of erosion and suggest that they once extended farther to the north.

Rate of Thinning at the Present Margins.

A method of attacking the problem of the original limits is found in the rate of thinning at the present margins. The data for determining this is, however, somewhat meager and not as accurate as is desirable for reliable results. It further rests upon the assumption that the thinning shown near the present margin continued uniformly to the original limits, an assumption which certainly is not exactly true, but which on the other hand serves as an approximation. The determinations check fairly well with the other indications and thus the arguments gain accumulative strength. The data of this nature are as follows:

The upper Devonian rocks in Pennsylvania and Maryland thicken in general from northwest to southeast. In Maryland the extreme easternmost outcrop is the thickest. Here therefore the axis of subsidence was to the east of the present eastern outcrop and later complete erosion has advanced westward beyond the line of maximum thickness. This may possibly be true in northeastern Pennsylvania also, but in Perry County on the Susquehanna, in central eastern Pennsylvania, a thinning exists toward the margin. Through Pennsylvania it seems probable therefore that the axis passes under the anthracite coal basins. This strikes east of the limiting outcrops in Maryland and agrees with the indications from that region as to the location of the axis. The eastern side of the original basin of sediments seems consequently in eastern Pennsylvania not to have been wholly destroyed. More carefully measured sections on the two sides of the coal basins are needed however to establish this view. The data supporting it rest at present, so far as known to the writer, upon the sections measured by Claypole in Perry County. He notes the difficulty of obtaining reliable measurements in this intensely folded and somewhat faulted district. Allowing for these difficulties as far as possible, he states that above Newport on the Juniata river the thickness of the Portage-Chemung rocks is 3300 feet. In the southernmost outcrop, some sixteen miles distant toward the

ancient land they measure but 1100 feet.* The Catskill rocks are given by Rogers as 6000 feet thick at the Susquehanna Gap above Harrisburg and Claypole gives this figure for the whole of Perry County.† A large part of the thinning of the Portage-Chemung to the southeastward is doubtless due to the passage of beds into the Catskill facies in that direction as observed both to the northeast and southwest.

The sum of the Upper Devonian rocks in the northern part of Perry County as derived from these measurements amounts to 9400 feet. Sixteen miles south at the Susquehanna Gap it is 7200 feet. The amount of shortening due to folding on this line was measured by the writer from the sections by R. T. Chamberlin.‡ The base of the Catskill was used for this purpose and it was determined that 21·5 miles had been shortened to 16 miles, 75 per cent of the original length. Assuming that the thinning is accurately determined and not in part due to a greater pressure on the east during folding, it gives a rate of 2200 feet in 21·5 miles, approximately 100 feet per mile. This is a higher rate of thinning than is observed anywhere toward the west, on the western side of the basin. There the highest rate, as seen between the anthracite basins and the Allegheny front, is not more than 60 or 70 feet per mile. A higher rate on the eastern side of the basin is however quite possible, and since this is near the center of the basin the rate may have increased to a still higher figure farther east. A higher rate of thinning than 100 feet per mile is not demanded, however, by the other lines of evidence. This would bring the original margin approximately to a line passing through New York, Philadelphia, and Baltimore, the margin of the present Coastal Plain. If the crust was shortened 25 per cent by the later folding of this zone, it would bring the original limit to a present line 15 to 20 miles northwest. This is the position shown on the map, fig. 1 (p. 225). In a later part of this article it is shown that the sources of erosion were southeast of the margin of the present Coastal Plain from rocks whose foundations are now concealed. Consequently the sediments either approached to the region of the present Coastal Plain or there was in the Upper Devonian a more or less broad neutral zone between the regions of erosion and deposition.

The bearing of lithologic evidence from the Green Pond Mountain outlier is considered in the next section, but such discussion as deals with the thinning of the strata may be given here. The marginal Upper Devonian outcrop in New York

* Second Geol. Surv. Pa., vol. F–2, pp. 71, 164, 1885.

† Loc. cit., pp. 34, 36, 244, 316.

‡ The Appalachian Folds of Central Pennsylvania, Jour. Geol., xviii, 233, 1910.

and Pennsylvania opposite the outlier has a thickness between 5000 and 6000 feet. The Upper Devonian in the outlier is estimated as still 2500 feet thick and an unknown portion has been eroded at the top. If the original thickness of the Upper Devonian be assumed here as only 2500 feet, and the formation regarded as part of a general mantle of sediments, it gives a thinning of about 3500 feet in 28 miles after folding. Assume this to be 35 miles before folding and the thinning comes to 100 feet per mile; the same figure as from Perry County, Pennsylvania, 150 miles southwest. This, it will be noted, is a maximum estimate. More probable figures for the rate of thinning near the present outcrops would be 80 feet for each mile of original distance. This may have steepened to a higher figure near the margin.

The rate of thinning at the northern margin, where the rocks are not much folded, may be approached from another standpoint: that of the dips in the successive formations. In southern New York the upper Devonian beds are known to thin from east to west, the Portage beds, for example, thinning westward from 1500 feet to 1200 feet in fifty miles, from long. 77° to 78°. This, therefore, is on the farther side of the geosyncline. The rate of thinning to the north is, however, more difficult to determine since the same bed is not exposed over great distances in that direction and gentle folds slightly warp the strata. In the higher strata, however (the basal Mississippian), the regional dips are to the southwest at an average of about 20 feet to the mile. In the Middle Devonian the dips average in direction 20 to 30 degrees nearer south and at average inclinations of from 30 to 50 feet per mile. These figures give between long. 76° and 78° a thickening of the Upper Devonian to the south-southeast, at a rate of from 20 to 30 feet per mile. In western New York south of Lake Erie, G. D. Harris gives data* from which it may be computed that the rate of thickening of the Middle and Upper Devonian together is 36 feet per mile to the southeast. Data given in the Warren, Pa., folio, however, make this seem somewhat high. These results serve as checks to the contour lines of the structure map accompanying the present paper, which are primarily based on measured or estimated sections and indicate a marginal rate of thinning of 22 to 23 feet per mile. It is possible that the thinning may have been accentuated beyond the limits of the present outcrops. It was not, however, the direction from which the sediments were dominantly derived, and from the absence of diastrophism in that direction a smaller rather than a larger rate of thinning in the portion now eroded might as readily

* Notes on the Geology of Southwestern New York, Amer. Geol., vii, 164–178, 1891.

be postulated. Thinning at the rate of thirty feet per mile would carry the margin of the Upper Devonian to the northern shore of Lake Ontario over Ordovician rocks, and over the southern part of the pre-Cambrian now exposed in the Adirondacks. A rate of 20 feet per mile would carry the margin some thirty miles farther north. The regional dip of the base of the Lower Devonian would project such a marginal extension upward high over the pre-Cambrian as now exposed. The present elevated position of the pre-Cambrian in that region cannot date back to the Devonian, so that this degree of extension of the Devonian strata meets with no structural difficulty.

Evidence from the Green Pond Mountain Region.

The discussions on the original limits of the Upper Devonian, based on the evidence of the margins, have been of the nature of an extrapolation, determining the rate of changes at the margin and projecting them to their limits. To give confidence to such conclusions they must be supported by independent lines of evidence. One of the strongest of these is found in the sediments of the Green Pond Mountain outlier, downfolded and downfaulted into the pre-Cambrian rocks twenty-five miles southeast of the marginal outcrop of the Catskill formation. The present isolation of the syncline and the different character of many of the formations within it have led a number of geologists to the opinion that this was a separate basin of deposition. In regard to this view, however, Kümmel and Weller state:

"Darton and Walcott have held that the rocks of this region, at least those subsequent to the Cambrian limestone, were deposited in an inlet separated by a land area on the west from the great sea, which lay still further west. We have observed no facts in the New Jersey area which necessitate this assumption. On the contrary, we believe that the weight of evidence there favors the view that these formations were formerly continuous with the corresponding beds in the Kittatinny valley and northwestward. Recognizing, however, that the evidence in New Jersey is not decisive, and not having had an opportunity of examining critically the field in New York, we are unwilling to oppose the conclusions of these workers, although from what we have seen we are inclined to believe that the facts are capable of a different interpretation from that of Mr. Darton. In any event, there can be no doubt but that the seas in which these beds were formed had a much wider extension than the present area of the formation." *

A discussion of the stratigraphy as given below suggests that the conclusion of Kümmel and Weller may be more positively

* The Rocks of the Green Pond Mountain Region, Ann. Report New Jersey Geol. Surv. for the year 1901–1902, p. 40.

held, and that the differences in the rocks are such as are to be expected under the view that they were deposited nearer to the sources of erosion, but existed in continuity with synchronous sediments laid down in Pennsylvania. Grabau also has recently urged the view regarding the continuity of the Silurian rocks of this axis with those to the west.*

The history of the region must be traced from the Silurian. Early in the Silurian the Green Pond conglomerate was laid down with a thickness of 1200 to 1500 feet.

"This consists of coarse, silicious conglomerate, interbedded with and grading upward into quartzite and sandstones. The pebbles of the conglomerate range from one-half to three inches in diameter, and are almost entirely white quartz, but some pink quartz, black, white, yellow and red chert, red and purple quartzite, and a very few red shale and pink jasper pebbles occur. The white quartz pebbles have frequently a pink tinge on their outer portion. At Gould's quarry large masses of the underlying limestone are included in a conglomerate, which is believed to be the basal layers of this formation.

"The matrix is comprised of quartz sand, is vitreous in texture and generally of a dull red color, but white, gray and greenish strata frequently occur, particularly in the basal portion, so that the formation is not so exclusively red as implied in most of the earlier reports." †

The Shawangunk conglomerate and sandstone, in similar stratigraphic position, outcrops twenty miles northwestward, is 1500 to 1600 feet thick, but is without the red color,—consisting of cleaner, whiter sand and smaller quartz pebbles. This contrast suggests either that the Shawangunk has been subjected to the greater sorting due to wave action and contrasts with a fluviatile origin of the Green Pond conglomerate, or that the latter corresponds to the red upper portion of the Silurian sandstone to the west, the basal portion being absent in the Green Pond axis.

The evidence shows that in neither the Green Pond axis nor to the west is the material of local origin. An enormous quantity of rock and from a considerable area has been destroyed to supply this mass, the pebbles consisting dominantly of white quartz-vein material from crystalline formations. Considerable transportation has been necessary in order to segregate it from the vastly greater quantity of finer grained and softer rock with which it was associated, a transportation to which the rounded form and resistant character of the pebbles bear witness. Furthermore, except to some degree at the unconformable base, local bowlders are not encountered

* Early Paleozoic Delta Deposits of North America, Bull. Geol. Soc. Am., xxiv, 477–479, 1913.

† Kümmel and Weller, loc. cit., p. 9.,

within it, nor is any change along the axis of the syncline to be noted which suggests that the sands and gravels were deposited in a narrow inlet, subject to lateral transportation of sediments and weak wave action.

The Green Pond conglomerate is overlain by the Longwood shales 200 feet in thickness and of red color, succeeded by the Decker limestone 50 feet thick, and carrying Cayugan fossils. Above the Decker limestone occurs the Kanouse sandstone (Newfoundland grit of the New Jersey report) 215 feet in thickness and carrying a mixed Oriskany–Corniferous fauna. The sequence is thus similar to that of the main Appalachian geosyncline but the beds above the Silurian conglomerate are thinner and certain horizons are probably missing. There is, however, no suggestion of local sediments from the walls of an estuary. On the contrary, the evidence suggests that the region lay nearer to the land of Appalachia and the bottom was less subject to subsidence. Hence thinner deposits of sediment were apt to be laid down and the material on the whole was coarser and less calcareous. Over such a zone the minor crustal oscillations are more apt to bring about temporary erosion followed by overlap. Certain beds above the Longwood shales appear to be absent in places.* In this region, Darton notes the difficulty of discriminating between overlap and overthrust, but states that on the northwest the Helderberg limestone rests directly on Cambrian limestone with no possibility of an intervening fault.† This suggests a pre-Helderberg warping of some extent, perhaps while the Green Pond conglomerate was still an unconsolidated gravel. In this region the Hamilton is represented by the Pequanac shale (Monroe shales of Darton), consisting perhaps of a thousand feet of dark, thick-bedded shale, somewhat sandy toward the top and containing a Hamilton fauna. According to Darton it also overlaps all of the preceding formations,‡ but the character of the sediment, like that of the preceding formations, does not indicate a local source. This is the last overlap known, as the Pequanac shale grades up into the Bellvale flags, a formation between 1600 and 2000 feet in thickness. The lower part of the Bellvale flags contain a Hamilton fauna. Plant beds of middle Devonian age are found in this formation, marine fossils fail in the upper portion, and it seems possible that here the continental phase of sedimentation began before the close of Hamilton time. So far as known there is no diminution in the thickness of the beds of the Hamilton group in passing eastward from the Delaware River, where

* Kümmel and Weller, loc. cit., p. 20.

† Geologic relations from Green Pond, New Jersey, to Skunnemunk Mountain, New York, Geol. Soc. Am., Bull., v, 391, 1894.

‡ Loc. cit., p. 392.

they measure about 2000 feet, but the strata there remain fossiliferous into Portage time.* The Bellvale flags grade in turn into the massive Skunnemunk conglomerate with an eroded top, but still 2500 feet in thickness in the deepest part of the syncline. The broader structural evidence indicates no local source for these conglomerates, since the fine grain and fossiliferous character of the Hamilton beds gives no suggestion of a mountain-walled inlet. No overlap suggests later deformation, and the Skunnemunk conglomerate was separated from the Green Pond conglomerate and the Archean by from 2500 to 3500 feet of Middle Devonian strata.

Although no local basin existed, the evidence indicates that continued upwarping of the land to the east exposed earlier quartzites to erosion, for the pebbles in the Skunnemunk are less abundantly white quartz, but principally of quartzite. As seen in the southern end of Bearfort mountain in New Jersey, the quartzite pebbles are dominant to the base. The section of Skunnemunk mountain, however, 27 miles northeast shows in the lower beds pebbles up to three inches in diameter, dominantly of white quartz, but with some pale pink and gray quartzite. The upper beds are much more abundantly conglomeratic, with quartzite pebbles as the dominant constituent and ranging in size up to eight inches. All are well rolled, prolate spheroids being the common form.

According to Kümmel and Weller, many of these pebbles are lithologically identical with the quartzite beds in the Green Pond formation, and seem to have been derived from it. The writer has observed internal evidence, however, which points strongly to a different and somewhat distant source. The pebbles in the Green Pond conglomerate are overwhelmingly white quartz. At the time of the deposition of the Upper Devonian the Silurian conglomerate had not become buried over 3000 feet nor subjected to mountain-making movements. If it supplied the material for the upper formation the white quartz pebbles would have had at that time greater resistance and coherence than the sandstone matrix and should apparently have contributed more conspicuously to the overlying conglomerate. Furthermore, the quartzite pebbles of the Skunnemunk are well rolled, implying considerable wear before deposition, and the grain of the quartzite pebbles is fine and somewhat more vitreous than the matrix in the dominant beds of the Green Pond conglomerate. A more positive indication is derived however from color. The matrix of the Green Pond conglomerate is a purple-brown with tinges of deep red, the few lighter colored beds not being volumetrically important.

* C. S. Prosser, The Devonian system of eastern Pennsylvania and New York, Bull. 120, U. S. Geol. Surv., p. 12, 1894.

The original color of the Skunnemunk quartzite pebbles, on the contrary, was a grayish white to greenish gray, stained later to a purplish or pinkish white, lighter in color value than the matrix of the Green Pond conglomerate. The evidence for this conclusion is as follows:

The lower part of the Skunnemunk conglomerate contains beds of green flags and greenish conglomerates well shown west of Hanks Pond and along the carriage road leading to the summer residence of Mr. R. F. Cross. In this greenish conglomerate the quartzite pebbles, the same in texture and size as in the purple beds above, are grayish white or greenish gray. In the purple beds they are whitish pink or purple. The vein-quartz pebbles are white in all cases, though stained a little on the outside and on internal fracture surfaces. The larger quartzite pebbles, especially in the beds only slightly ferruginous, are pale in the center with a purple rind on the outside.

The logical explanation of these facts is based upon the observation that white vein quartz is not porous and hence does not stain readily by taking up solutions of iron in the ground water. Quartzites, on the contrary, show various degrees of porosity, from sandstones, the most porous of rocks, to vitreous quartzites, almost without porosity. Ferruginous solutions becoming oxidized in sands and gravels stain them yellow, as seen in the yellow gravels of the Atlantic Coastal Plain. This stain permeates the porous pebbles in direct ratio to their porosity. Subsequent diagenesis in the ancient formations has eliminated the water from the iron oxide and turned the yellow of limonite to the reddish brown or purple of hematite, which if diluted by the rock substance becomes pink or pale purple. In the Skunnemunk conglomerate, although the matrix is of about the same depth of color as in the Green Pond conglomerate, only a few pebbles attain this same depth of stain, most of them remain distinctly lighter, and some of the greenish, jaspery pebbles do not change in color except on the surface.

The Green Pond conglomerate, of the Silurian, rests unconformably upon pre-Cambrian gneiss and Cambro-Ordovician limestone, the basal Cambrian quartzite in New Jersey being very thin and in many places wanting. The material of the Silurian is apparently derived from deep erosion of these gneisses at some distance to the southeast, sufficient to permit the segregation and rounding by transportation of the white vein quartz which is a minor constituent of the gneisses.

In regard to the Skunnemunk conglomerate, of Upper Devonian age, the evidence shows that most of it was not derived from a local source; neither the pre-Cambrian gneisses,

nor the Green Pond conglomerate. On the contrary, quartzite formations resembling Cambrian quartzite where these are extensively developed, had become uplifted and subjected to erosion. Such a supply of material could not have existed short of some region now concealed by Coastal Plain deposits or the waters of the Atlantic ocean.

Gravels as coarse and thick as those of the Skunnemunk formation are commonly developed skirting the larger mountain ranges, swept out by rivers and forming piedmont slopes. From the Himalayas they are swept southward in abundance 20 to 30 miles. In the basins of Asia from ten to forty miles is a common distance. In the valley of the Po, Bonney has noted that gravels with pebbles commonly 3 to 4 inches in diameter and more, reaching rarely 8 inches, are found after the river and its tributaries have flowed over from 35 to 50 miles of plain.* Gravels in some instances are carried much farther, even several hundred miles, but in such cases the pebbles are small and constitute a lesser proportion of the entire deposit. The well-worn and rounded character of the Skunnemunk gravel indicates that it had suffered a large reduction in size of pebbles and had been moved a considerable distance. The margins of the gravel plain may therefore be estimated at perhaps from 20 to 35 miles to the southeast of the Green Pond syncline, making the original limits of the upper Devonian deposits from 45 to 60 miles southeast of the present outcrops in Pennsylvania. Considering all the lines of evidence, especially the distance to an available source for the quartzite and the shortening of this distance due to later folding, the larger figure seems more probable than the smaller. Sixty miles during the final period of folding may well have been shortened to forty-five miles, so that this has been used as a minimum limit in locating the original margin in New Jersey and Pennsylvania. The distance to the northwestern edge of the crystalline floor concealed beneath the Coastal Plain is now about sixty-five miles, and from beyond this line it would appear that the greater portion of the quartzite must have been derived.

Relations of Piedmont Gravels to Climatic and Crustal Movements.

Broad piedmont plains, such as those which skirt the east side of the Rocky Mountains and whose dissected surfaces form the High Plains, are in delicate adjustment to the grade of the rivers which built them. A climatic movement away from a state of semi-aridity toward a rainy and humid condition increases the hold of vegetation on the soil, decreasing the

* Rounding of Alpine Pebbles, Geol. Mag., decade III, vol. v, p. 58, 1888.

washing of upland waste into streams, while at the same time the capacity of the streams to carry waste is increased. The rivers consequently load up by eating into the higher parts of the piedmont slope, the more readily because of the unconsolidated nature of the deposits; the river grade outside of the mountains is flattened and there is a transfer of coarser material to the delta or the sea. A conglomerate of climatic origin is the result, interbedded with normally finer grained deposits. A reverse climatic movement will build up again the higher parts of the slope, steepening the grade in this part and giving a minimum supply of waste to the delta until equilibrium between grade and climate is established. In general it may be said that climatic fluctuations of any nature will produce alternate terracing and filling in the upper parts of the piedmont plain; a synchronous alternation of thick and coarse with thin and fine deposits upon the delta topset beds, both on the land and extending to the shallow sea.

The repeated cutting and filling during the Pleistocene of the valleys crossing the High Plains seems, as W. D. Johnson has pointed out, to have been most largely of a climatic cause, and the same conclusion has been reached for the terracing in other regions by Davis and Huntington. The subject has been discussed more fully by the writer elsewhere, with some application to the Appalachian deposits of the Upper Paleozoic.*

The question arises, how such a climatic record may be discriminated from a somewhat similar record made as the result of crustal movements. The clearest distinction is in the relations of carbon and iron oxide as seen in the shale members of the delta deposits; an increase in the quantity of carbon marking a movement toward wetter or cooler climates, an increase in oxidation marking the movement in the contrary direction.

The results to the delta would be quite different if there were no storage of coarse siliceous waste in a piedmont slope between the mountains and the alluvial flats beyond. Then the movement toward a greater growth of vegetation would normally decrease the supply of coarse waste to the rivers and increase the deposit of carbon to the delta. Certain exceptions may, however, be imagined:—a climatic movement which would bring on glacial conditions in the mountains would carry coarser waste farther from them without deriving such from a piedmont slope and at the same time favor the storage of carbon in the parts of the delta which did not receive this waste. Alluvial gravels of ultimate glacial origin derived from a crys-

* Barrell: Relations between Climate and Terrestrial Deposits, Jour. Geol., xvi, pp. 162, 163, 363–384, 1908.

talline upland would, however, show a greater dominance of granite or gneiss cobbles over those of vein quartz as compared with gravels due to normal weathering and previously stored by rivers in a piedmont slope. The character of the silt in the two cases would also be different. Again, if vegetation had not evolved to that state where, under a favoring climate, it could bind the soil, a movement toward a cooler and wetter climate, even without glacial conditions, might lead to more rapid instead of less rapid erosion of the uplands. In that case, however, coarse and fine detritus would both be carried to the delta and clean formations of sand and gravel would not be conspicuous.

The more normal and probable relations of climatic fluctuations to mountain, piedmont, and delta which were first stated will be assumed to have existed during the later Paleozoic and the justice of that assumption tested by the degree to which its expected results accord with the observed stratigraphy of the delta plain and shallow sea. If the theory that pulses in climate are recorded in sedimentation be regarded as sound, it may then be used in two ways in the interpretation of the past:—the deposits of an ancient delta may contain a climatic record and at the same time testify to the former existence of a piedmont now destroyed as the result of orogenic movements and later erosion. It is from this standpoint that the subject enters into the present problem.

The Catskill red shales and gray sandstones are succeeded by the Pocono sandstones and conglomerates. The Pocono formation spreads across the state of Pennsylvania, but the beds in the east are coarser and thicker than farther west. Shale is much diminished in amount. Most of it is olive, though, especially in the western half of the state, considerable red shale occurs. Scanty coal seams show for their times and areas the presence of perpetual swamps. This Pocono sandstone plate is abruptly followed by the Mauch Chunk red shale and red sandstone; brilliant with ferric oxide, containing lime, gypsum and salt, with mud-cracked strata in place of coal. This formation closed the Mississippian period. The Pennsylvanian follows, inaugurated by the group of Pottsville conglomerates and sandstones with black shales and some coal, reaching a maximum thickness of about 1200 feet in Pennsylvania. This is succeeded by the coal measures. The whole series from the opening of the Middle Devonian reaches a maximum thickness in Schuylkill County, Pennsylvania, of more than three miles.

The red shale formations, the Catskill and Mauch Chunk, show transitions on the east into the overlying formations. The Pocono, on the contrary, passes abruptly at its top into the Mauch Chunk shale. Both the Pocono and Pottsville conglom-

erates are made up dominantly of much water-worn white quartz pebbles, and their whole areas are characterized by a great dominance of siliceous over argillaceous contents. All of these features correspond to the theoretic results upon a broad piedmont slope of increasingly wide swings of the climatic pendulum which carried the world from Upper Devonian warmth and semi-aridity to Upper Carboniferous humidity and possible coolness. Such are the major changes through the later Paleozoic; changes which find parallels in the geosynclines of the Maritime Provinces of Canada and of northwestern Europe. They form a crescendo leading from the Middle Devonian and terminating in the Permian, a period of mixed and unparalleled aridity and glaciation.

On these great climatic movements were superimposed the minor climatic rhythms and from them must be separated the effects of the crustal movements. In the continental interior, the region of shallow seas, the effects of diastrophism are more in evidence; an unconformity separating the Mississippian and Pennsylvanian and the latter exhibiting progressive overlap. The great thickness of the Pennsylvanian deposits of the south, measured by many thousands of feet, following the limestones of the Mississippian and the black shales of the Devonian, also testifies to great crust movements during the Pennsylvanian in those regions. The Pennsylvanian deposits of the Acadian and Boston basins seem also to imply orogenic movements of considerable magnitude in the north.

The facts which have been previously cited regarding the formations in eastern Pennsylvania seem, however, to correspond most largely to a climatic cause. The far-carried conglomerates and sandstones of the Pottsville associated with some black shales and coal; to a lesser degree the same relations in the Pocono, contrast with the absence of conglomerates in the Mauch Chunk, and the presence there of thick red shales and the marks of aridity. In the Catskill these features resemble the Mauch Chunk but conglomerates are not wholly absent on the east and the indications in the red shales are those of semi-aridity. The climatic control which explains these relations of conglomerates and shales also points strongly in consequence toward the former existence of a piedmont plain, now eroded, which during the Catskill and Mauch Chunk epochs became a storehouse of siliceous gravelly waste, which by the stronger rivers of the Pocono and Pottsville epochs was spread over the delta plain and given to the waves of the shallow sea. The amount eroded from the Piedmont slope was but a fraction of the volume of the whole deposit. It was that amount which was contained between the stable river grades before and after the climatic change. The

greater part of the piedmont remained unaffected save by crustal uplift, since it originated as a consequence of crustal downwarping in front of the mountains and all but its upper deposits were below any possible river base-level. The conglomeratic members of the Pocono and Pottsville are, however, hundreds of feet thick in eastern Pennsylvania, growing finer and thinner westward, but covering originally many thousands of square miles. Their volume implies, therefore, the former presence of a piedmont as wide and as high above sea level as has been indicated by the other lines of evidence.

The theory of the relations of climatic cycles to cycles in sedimentation converges to the same conclusion as the other lines of evidence regarding the former existence of a wide piedmont slope constituting an eastern side to the Appalachian geosyncline.

Volume and Sources of Upper Devonian Sediment.

Of the volume of sediments deposited in the Appalachian geosyncline during Middle and Upper Devonian time, Willis states:

"If this mass with approximately the dimensions with which it was deposited in the sea, could be restored upon a sea-level plain of Appalachia, it would constitute a mountain range closely resembling in height, extent and mass the Sierra Nevada of California."*

The writer has computed from the data shown in fig. 1 (p. 89) the original volumes of sediment within an area bounded by lat. 39° 30′ on the south, 43° on the north, and from the original eastern margin to long. 80° 30′ on the west. Within this area the map by Willis indicates a volume of 55,000 cubic miles. The Middle Devonian comprises about one-fifth of this, leaving 44,000 cubic miles for the Upper Devonian. On the map accompanying the present article there is shown within these boundaries 63,000 cubic miles of Upper Devonian sediment, an increase of 43 per cent over the estimate by Willis. Allowing for the extension which the present writer has given to the north the present estimate becomes readily as much as 50 per cent greater than the previous. This is an impressive measure of the volume of the adjacent land which was eroded in Upper Devonian times. But it is a minimum measure, since that part of the rocks which was taken into solution was carried farther away, and of the mechanical sediments it represents only that part which was carried westward into the trap of the geosyncline.

* Paleozoic Appalachia, Md. Geol. Surv., vol. iv, Pt. I, p. 62, 1900.

An adequate geologic source for this volume of material must be sought. In part the sand and clay may have come from a distance of hundreds of miles, but the gravels and the feldspar sand indicate that much of it was from a nearby mountainous tract whose rocks were in large part of quartzites, gneisses and granites. The questions, therefore, arise,—how far away was the field of great erosion? From what direction were derived the Upper Devonian sediments? Did they come from New England and enter the geosyncline by way of the Catskill Mountain region, did they come from some other distant source, or were they poured in from a longitudinal land mass lying along the southeastern side of the geosyncline?

If attention were confined to those lands now above the sea and to the portion of the Upper Devonian rocks still uneroded, a derivation of the sediment from the northeast would be favored. There is in New England a broad region of metamorphic rocks and the Upper Devonian sediments still uneroded show further that subaërial conditions began to prevail first in eastern New York, gradually advancing westward and southwestward. A closer examination shows, however, that these facts are not real evidences of a derivation from the northeast. The strike of the New England rocks is southward under the submerged portion of the Coastal Plain. The Coastal Plain deposits rest on a surface which indicates profound erosion previous to Comanche time. The fact that the Coastal Plain in southern New England is diagonal to the structure and hides the older basement to the south indicates the lack of relation to the distribution of lands in Paleozoic time. The structure of that basement is the more significant feature.

The Catskill shore line advanced westward during the Upper Devonian past the axis of deepest and most rapid subsidence and encroached on the less rapidly subsiding sea bottom beyond. This is true in New York, in Pennsylvania, and in Maryland. If the sediment had been derived from the northeast the advancing shore line would, on the contrary, have been different from what is observed to be the case. The great zone of subsidence in southeastern Pennsylvania would have long remained as sea. The shore line would have trended east and west, advancing south, and a terrestrial phase in Maryland would have been deferred until the marine phase had entirely disappeared to the north. On the contrary, the Pawpaw–Hancock quadrangles show that the Catskill conditions in Maryland appeared in full force on the east, where lay the zone of greatest subsidence, before they encroached westward. The Catskill beds are also much thicker to the east, being given as 3800 feet in the eastern part of the Hancock quadrangle and thinning to 2000 feet within a distance of 15 to 20

miles northwest.* The delta in Maryland and southern Pennsylvania grew, therefore, from the southeast against and past the zone of maximum depression. From the southeast, consequently, the sediment was brought and in great volume. The appearance of the subaërial conditions first in eastern New York is adequately accounted for, first, by the more rapid subsidence of the basin in Pennsylvania; and second, the subsequent erosion there of its whole southeastern side, where terrestrial deposition must have prevailed before it reached the middle of the basin. After the subaërial conditions became established in eastern Pennsylvania as far as the region of greatest thickness the advance of the shore line was northwestward, contrasting with the initial western advance in New York.

The gradation in the coarseness of the sediments agrees with the indications of the shore lines. It is the eastern outlier which shows the only striking conglomerates. In the main areas the gray sandstones with fine-grained conglomerates dominate on the eastern side of the southern anthracite basin, far removed from the region of the Catskill Mountains. In Maryland the eastern outcrops show a less arenaceous nature than do the eastern outcrops in central Pennsylvania, but on the strike of the later folding they correspond to a more western part of the formation in Pennsylvania. A wider eastern zone may therefore have been eroded in Maryland, following the Permian folding. The sediment did not however come from the region of the present Southern Appalachians, since marine conditions prevailed longest in the south, the Catskill disappears in Virginia, and in Tennessee the Upper Devonian is represented merely by a thin black shale. In general the Paleozoic sediments of the Appalachian geosyncline do not show transportation along its axis from the north or south, but transference into it from a land parallel with it. The axis of upwarp and that of downwarp seem in fact to have been genetically related, as is so commonly the case in the present mountain chains.

The indications given by the directions of delta growth, thickness of the Catskill beds, and the gradations in their texture, are, therefore, that the sediment was brought in along the whole front of the geosyncline by more than one river and from the southeast as well as the east and possibly northeast. The result was a confluent piedmont plain and delta front building out a terrestrial coastal plain. More detailed study may be able to locate the several centers of principal delta growth.

* Stose and Schwartz, U. S. Geol. Surv., Folio 179, pp. 12, 13, 1912.

The rivers do not appear to have been great continental water-ways. Such are far apart in their mouths, corresponding to the size of their drainage basins. The bulk of the sediment of such rivers is mud and silt. They corrade their way across mountains at a low grade and would not be capable of building sloping piedmont plains. Furthermore the coarseness of the quartzite bowlders in the Skunnemunk conglomerate is such that rivers probably did not carry them from the mountains more than 75 or 100 miles. For the sources of erosion we must look east and southeast from the geosyncline, toward a parallel and not far distant mountainous land.

Let the attention be turned next from the sediments to the terranes beyond which could have supplied them. The geologic maps show that within the zone once covered by the Devonian piedmont gravels, Cambrian and Ordovician rocks still remain over considerable areas, and evidence has been given that the pre-Cambrian ridges of gneiss east of the Schuylkill river were mostly mantled by younger formations up to Jurassic times. West of the Schuylkill the prevailing formations within the original Upper Devonian limits are Ordovician rocks. Even, therefore, if previous arguments had not indicated that this zone was a region of deposition, it could not be regarded as a field of supply for an appreciable portion of the sediment.

Passing next to a zone to the east of the last and beginning at the north, it is to be noted that the pre-Cambrian rocks of the Green Mountains are of comparatively small areas. As far east as the valley of the Connecticut and as far south as New York city, large areas of Cambrian and Ordovician schists remain. South and east of New York City the ocean and the deposits of the Coastal Plain largely conceal the older structures; but, beginning at Trenton on the Delaware River, the ancient rocks reappear between the Triassic and Commanche overlaps, constituting an exposure of gneisses and granites widening southwards through Pennsylvania into the Southern Appalachians. Near the Delaware state line, however, a few outliers of Cambrian quartzite and limestone still remain, and immediately west are large areas of metamorphosed Ordovician rocks. This exposed belt, about 25 miles wide, certainly suffered very considerable erosion in early Triassic and again in Jurassic times. There is no evidence that it was covered by Upper Devonian sediments, but neither could it have suffered much from Upper Devonian erosion. Thus, by a process of exclusion, for the zone of mountains which supplied this waste we must look farther to the eastward, at least as far as eastern Connecticut and the region now overlain by the strata of the Coastal Plain. This could have been

but the margin of the vast volume eroded; the land now hidden beneath the waters of the ocean must have been the chief source of supply. In Maine, New Brunswick, and Nova Scotia igneous activity is known to have prevailed in the Devonian. The rocks of these provinces and of Newfoundland, the latter structurally the eastern outpost of the continent, strike southeastward under the sea and toward the region from which presumably came the sediments of the Catskill formation. It would seem further that to such a zone beyond the margin of the Coastal Plain of New Jersey must we look to locate the source of the great volume of gray quartzites which supplied the pebbles of the Skunnemunk conglomerate. No adequate formation is known to the east upon the land, but pebbles of Cambrian quartzite, thought to have come from the east, are found in the Carboniferous conglomerates of Rhode Island and from that direction Woodworth thinks probably came the greater volume of material which filled the Rhode Island basin.

Lack of Relation of Appalachia to the Continental Shelf.

The Control by the Continental Shelf on Paleogeographic Maps.

The doctrine of the permanence of the continental platforms has been held rigidly by many American geologists. Starting in the past century with the recognition of the evidence that the continents have never been the beds of deep oceans, but have been flooded merely by shallow seas; the corollary was attached that consequently the beds of the deep oceans had never been land surfaces. Yet this is not a necessary consequence of the original proposition and has in reality no similar direct evidence to support it; except that basins must have existed sufficiently large in former ages to hold the ocean waters which were then upon the earth. But in the balancing of losses and gains to which the surficial water is subject, it appears probable that the gains have notably exceeded the losses through geologic time. To a somewhat greater degree than this the ocean basins can have increased in volume.

As evidence opposed to the hypothesis of an unchanging form of the ocean basins, many examples have been noted of extinct and living faunas showing their closest affinities on the opposite sides of present ocean basins, or isolated on oceanic islands. The affinities are so special in some cases that many even of the strongest adherents of the doctrine—that both continents and oceans have always been outlined in their present relations—admit some degree of connection of former lands. Yet where land bridges are not required, paleogeographic maps

have held rather closely to the present margins of the continental platforms. In the absence of evidence of a former extension of the land beyond these margins this procedure is no doubt the wisest and without it as a point of departure each different map would represent guess work and not science. But undue importance finally becomes attached to a conclusion for which there is only negative evidence. Thus it has been customary to regard the land of Appalachia, which through the Paleozoic shed sediments westward into the geosyncline, as confined to the area of the present continental platform, although from Nantucket to North Carolina the submerged shelf to the hundred fathom line is but approximately 75 to 80 miles in width.

Breadth of Appalachia implied by the Volume of Sediments.

The present investigation tends to limit the fields of erosion during the Upper Devonian to those ancient terranes now hidden beneath the Coastal Plain and the sea, leaving a width of not more than 125 miles opposite Pennsylvania to supply the great volume of sediments. In fact, if it be assumed of such a marginal region that half of its width shed its waste eastward into the Paleozoic Atlantic, it leaves a maximum width of but 60 miles, to have yielded the sediments which in the Upper Devonian alone were greater in volume than the entire Sierra Nevada. Over New England the available zone within the limits of the continental platform was much wider, but reasons have been given for believing that a large supply of the Upper Devonian sediment of Pennsylvania and Maryland came from the east and southeast.

If the present margin of the continental platform has held approximately its present place since the Upper Devonian, as many paleogeographic maps imply, it means, allowing for a certain breadth of shelf at that time, that Appalachia must have been still further restricted in width. As a quantitative test of such a view assume Appalachia from Rhode Island to Virginia to have been a mountain system 100 miles wide. Consider it an isosceles triangle in vertical cross section, and giving as much waste to the east as to the west. The Upper Devonian sediments between lat. 39° 30′ and 43° and east of long. 80° 30′, approximately the limits of the map, fig. 1, are computed to have had an original volume of 63,000 cubic miles. Neglecting the outlying portions, although these are of great thickness in West Virginia; assume that this sediment is equal to the volume eroded from the western side of Appalachia over a length of 500 miles, from southern Maine to the coast of southern Virginia,— the sediment thus converging into the geosyncline. The computation shows

that the crest of Appalachia would have had to be lowered five miles to supply this much of the Upper Devonian sediments. It is seen from the assumptions that this is a minimum estimate and might readily be increased fifty per cent or more. The easiest escape from these quantitative difficulties is to conclude that there is no relation between the Atlantic boundaries of Appalachia and the present coastal shelf. It would seem that the Upper Devonian slopes leading toward the geosyncline was probably as much as 100 miles wide instead of fifty miles as assumed and that the divide of the drainage was at least as far east as the present 100 fathom line southeast of Long Island and New Jersey. The eastern slopes of Appalachia in that case existed where now is deep ocean. The disproportion between the volume of the sediments in the geosyncline and the present area of the continent to the southeast emphasizes the query raised by Gilbert in 1892, whether Appalachia must not have extended into the present ocean basin in order to provide an adequate source for the Paleozoic sediments.*

The Shelf a Terrace of Post-Paleozoic Construction.

As another line of investigation bearing upon the problem, the nature of the continental shelf should be considered.

Ocean waves are known to have a perceptible effect to a depth of about 100 fathoms, planing away the shore and the higher parts of the bottom, carrying the products of fluviatile and marine erosion outward to deeper water. The waves move material along the bottom and prevent the settling of the finest silt until the limit of wave action is reached. Beyond that limit the bulk of the material is rapidly deposited from suspension. In protected situations this depth becomes less and in many places is not over fifty fathoms. There is thus built outwards around the continents a subaqueous terrace, its top gently sloping to the depth of 100 fathoms or less, its front much steeper in comparison, and giving sharpness to the continental margin. The doctrine of the permanence of this line through geologic time implies that the constructional additions are insignificant. But the volumes of sediments which age after age have been poured into continental geosynclines must correspond to other volumes swept out to the borders of the ocean basins. Unless isostatic sinking under the load of sediment compensated progressively for the outbuilding of the terraces, the continental shelves, if ancient lineaments, would have widened on the average by some hundreds of miles during the course of geologic time. If there is isostatic sinking it is

* Continental Problems, Geol. Soc. Am., Bull., iv, 187, 1893.
Professor Grabau also has called attention to this significance of the great volume of Paleozoic sediments.

not so pronounced as to mask the constructional nature of the terrace, as shown by the relation of its upper surface to wave action.* To what extent then are the continental terraces constructional features controlled by erosion and sedimentation, and what are the limits which isostasy places upon them? The answer must satisfy the evidence of both geologic and geodetic nature. It will depend to a considerable degree upon the prevailing conceptions on the rigidity of the crust, as measured by the area and thickness of load which may be piled up before sinking of the foundation begins to keep pace with further loading. In order to gain such an answer the writer has investigated the subject under a separate title.† The results derived from both geologic and geodetic evidence, contrary to

FIG. 5.

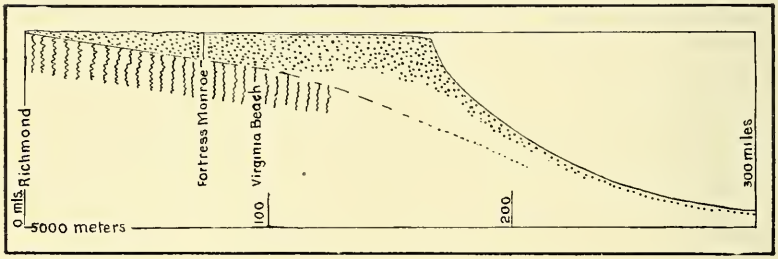


FIG. 5. Section of the Coastal Plain and Continental Shelf through Richmond and Fortress Monroe, Va.; vertical scale multiplied by 26.

some recent statements, indicate that the crust now sustains in places loads represented by several thousand feet of rock over areas of several tens of thousands of square miles. Judged by this measure it is quite possible that the continental shelves may be in places constructional features built far outward and upward; changing what would otherwise be a gentler slope from continental platform to ocean basin into a pronounced subaqueous shelf and steeper distal slope.

In the light of this possibility, attention may be turned to the actual evidence and the inferences from that evidence as given by the Atlantic Coastal Plain and its extension in that part of the continental shelf southeast of Pennsylvania and Maryland. It is a region which has been free from folding since the Permian, from fracturing since the Middle

* Professor T. C. Chamberlin has discussed in current articles the significance of this surface of wave planation as showing a lack of control by diastrophism. See especially Jour. of Geol., vol. xxi, pp. 523–533, 1913.

† To be published in the Journal of Geology under the title,— "The Strength of the Earth's Crust."

Mesozoic; and the rivers during later time have carried to the seaboard great quantities of sediments. Wells penetrating the water-bearing strata show that a progressive tilting has gone forward since the close of the Jurassic, depressing under the Coastal Plain the erosion surface of Jurassic age and elevating the Appalachians. The information is most complete in Virginia on an east-west section, shown in fig. 5, passing through Richmond and Fortress Monroe. These two localities are on the two sides of the emerged portion of the Coastal Plain and 72 miles apart. At Fortress Monroe a deep well entered the crystalline floor below the sediments of the Potomac group at 2246 feet below sea level. The fresh-water beds of the Potomac are given there as 1300 feet in thickness, much thicker than at the outcrop. Numerous wells near the margin show that the crystalline basement has erosional irregularities amounting to several hundred feet. Their influence is, however, practically eliminated on this section because of the great depth of the well and its distance from the margin of the Coastal Plain. No warping apart from the minor irregularities is indicated between Richmond and Fortress Monroe as shown on the structure section recently published by the Virginia Geological Survey.* The Potomac formations, because of their fresh-water nature, have been held by many geologists to have originated in an estuary. Of a seaward barrier there is, however, no evidence. They are seen to thicken as far east as there is any information and the exposed sediments are best interpreted as the landward side of a delta plain skirting the rising Appalachians and built from their waste.† The erosion from the rising side and the deposition on that which was sinking would tend to promote the tilting. The building outward of the continental terrace would, from the standpoint of isostatic adjustment produce the greatest sinking of the floor under the outer part of the terrace, for there the departure from isostatic compensation is greatest. Such a curve to the Potomac floor is furthermore shown by fig. 5 to be necessary in order to carry the floor beneath the foreset slope of sediments. The adjustments, however, might be by distributive faulting instead of the smooth curve which is shown. It might further be largely due to internal movements which work in the direction of enlarging the ocean basin, and the sediments in that case may keep the surface far above isostatic compensation.

From these several lines of argument it is to be concluded that the Atlantic continental shelf is a subaqueous terrace built

*Samuel Sanford: The Underground Water Resources of the Coastal Plain Province of Virginia, Bull. No. 5, fig. 6, 1913.

† For a fuller discussion of this view see Barrell, Criteria for the Recognition of Ancient Delta Deposits, Bull. Geol. Soc. Am., xxiii, 405–411, 1912.

out since the Jurassic and extending the platform toward limits set by the resistance of the crust. The normal slope from the Appalachians to the ocean basin would in the present period be a much smoother and more gently sloping curve, although quite probably above the present level of the crystalline floor, if surface agencies had not planed across the piedmont on the one side and built out the shelf on the other. The surface of the latter holds then no relation to the limits of Paleozoic Appalachia.

The Ocean Basins widened by Continental Fragmentation.

The preceding arguments lead to the conclusion that the ocean basin has advanced inland since the close of the Paleozoic and that the seat of a part of the ancient land is now deep ocean.

This is in accord with the views of Suess, who holds that the Atlantic and Indian oceans cut across the Paleozoic structures and indicate a breaking down of the continental platforms since those structures were made. It is known also that close faunal relationships have existed in the past between northwestern Europe and northeastern America, implying some path of migration. On the maps by American geologists such a bridge has been shown as a more or less narrow connection circling Davis Strait and utilizing Greenland and Iceland as piers supporting a narrow causeway between North America and Europe. The structural evidence which has been considered would seem to show that such connecting lands may have been broader and more like the areas of the adjacent continental platforms, of which they in fact formed then a portion: at times, flooded in part by shallow sea; at times, in part the seat of ancient mountains.

Conclusion on Appalachia in the later Paleozoic.

The old-land of Appalachia during the Paleozoic tended to be a broad and mountainous upland. West of it was the trough into which much of its waste was poured. As in the Eurasian mountain system, when this trough collapsed it was underthrust. Appalachia was overthrust against it. The eastward-dipping folds and faults and the greater uplift and consequent erosion on the eastern side of the geosyncline were in response to this relation of anticlinorium and synclinorium and not to a thrust from the ocean. The ocean in fact need have had no more direct connection than it had in the Laramide overthrusting of the front ranges of the Rocky Mountains upon the Great Plains in the center of the North American continent, or the Neocene overthrusting of the Himalaya upon the plains of India.

The general conclusion to this article which perhaps is most impressive is that regarding the magnitude in breadth and in vertical relations of the ancient orographic elements and the

changes which each successive age has wrought. The record has been interpreted in terms of the great Tertiary mountain systems of Eurasia, consisting of their overthrust structures, piedmont slopes, waste-filled basins, and delta plains,—as the members of a greater system, each part bearing relations to the other. The fragmentary remains of late Paleozoic Appalachia and its waste which still exist, when pieced together in accordance with this pattern, rise to equal grandeur. An orogenic era began in Appalachia in the Devonian and spread as time went on. Great as was the Upper Devonian mountain building, it was limited and was only premonitory of the greater, wider movements of the Pennsylvanian. During the Upper Devonian the interior waters facing the southern Appalachians received only meager supplies of sediment. The crust was there at rest. But with the coming of Pennsylvanian times the mountain system lengthened to the southwestward and its curving arc finally embraced as far as Texas the interior continental basin into which it poured its waste. The Permian witnessed only the final collapse of the interior geosynclines and the inward march of the conquering mountains. The Appalachian revolution began in reality in the Middle Devonian, the first mountain bulwarks being thrown up on the far eastern side of the Appalachian system and to the north. There in Maine, New Brunswick, and Nova Scotia granitic intrusions and volcanic outpourings of Devonian age took place and in the nearby basins the waste resulting from uplift was laid down. The southern part of that system supplied the debris which filled the geosyncline in Pennsylvania.

Our knowledge of the Appalachians as a distinct mountain system begins with the opening of the Cambrian. The basal formations of the Cambrian, or late pre-Cambrian, thousands of feet in thickness, are geosynclinal deposits whose volume testifies to the destruction of great monntains to the east. Lesser movements took place at intervals and one of considerable magnitude at the close of the Ordovician. These, however, were relatively brief and minor orogenic manifestations. They were separated and obliterated by periods of prolonged quiet and erosion. They were more comparable in character to the movements of the Mesozoic and Cenozoic and do not rise to the prolonged growth and culmination of those greater revolutions which preceded and closed the Paleozoic Era. The latter, because of its completer record, has become known as *The* Appalachian Revolution and its earlier development in the Upper Devonian has been traced in this paper.

The Devonian mountains are gone, and where once they rose in defiant height their very foundations are broken and buried, but in remnants of formations born of destruction we may read the epitaph which records their greatness.

Yale University, Dec. 2, 1913.

Art. XVIII.—*Paleogeographical Affinities of the Alexandrian Series;* by Charles Keyes.

No more illuminating example exists emphasizing the urgent need of directly applying the broader paleogeographical principles to the solution of local problems in stratigraphy than that presented by recent attempts to deliminate sundry taxonomic groups of terranes in the continental interior.

For several reasons the Silurian section of northeast Missouri, for instance, is particularly instructive.* The sequence is so meagerly represented that it is all comprised within the vertical limits of barely a score of feet. The succession is divided medially by a marked plane of unconformity. There is, as we now know, an overlapping of a southern earlier Silurian deposition by a later northern Silurian formation. The special stratigraphic significance of these facts have a far-reaching bearing; and certain aspects may be briefly considered.

The section of the rocks in question and their immediate associations as displayed in the deep valley of Noix creek and elsewhere in the vicinity of Louisiana, in Pike County, Missouri, is essentially as follows:

Silurian Section in Northeast Missouri.

7.	Louisiana limestone	50 feet
6.	Saverton shales (green)	50
5.	Grassy (black) shales (Carboniferous)	60
	Unconformity.	
4.	Limestone, brown to reddish, heavily bedded (Devonian)	10
	Unconformity.	
3.	Limestone, buff, massive (*Bowling Green*, Silurian)	20
	Unconformity.	
2.	Limestone, brown, thinly bedded, locally oölitic (*Noix limestone*, Silurian)?	10
	Unconformity.	
1.	Shales, blue (Ordovician)	60

In this section Nos. 2 and 3 constitute the Edgewood formation of Savage.† The non-oölitic portion of the first named member is, by the same author, termed the Cyrene limestone.‡ Farther south, in southeast Missouri, is the Girardeau limestone. Together these three beds, and some others in northeastern Illinois, are grouped into the Alexandrian series,§

*Missouri Geol. Surv., vol. iv, p. 47, 1894.
†This Journal, (4), vol. xxviii, p. 517, 1909.
‡Bull. Geol. Soc. America, vol. xxiv, p. 361, 1913.
§This Journal, (4), vol. xxv, p. 434, 1908.

which is regarded of Early Silurian age. The Silurian strata of northwestern Illinois and northeastern Iowa appear to be of younger age.

When, several years ago, the principal Mississippian section* was described by me, the Silurian beds of the Louisiana district (Missouri) came in for incidental consideration only. The brown limestone (Bowling Green) was chiefly taken into account, since the oölite was regarded as merely a local and quite unimportant facies. In referring it to the Niagara horizon of the Iowa section† the lithology and lithologic sequence had to be mainly relied upon in correlation, because of the fact of an absence of fossils in it, and because there were present in the associated oölite many typical Silurian forms. Although evidences of unconformable relationships were noted at the time, it was not until several years later that the full significance of this feature was grasped.

Approaching the problem from a different direction, Savage‡ supplies us with very complete and valuable data for its correct solution; but he also gives as little attention to the significance of the massive upper member as was formerly attached to the lower oölitic layer. In consequence this author is induced to throw the entire Silurian section of the Pike County region into a single group—the Edgewood formation, and to parallel this terrane with that part of the section of southeastern Missouri above the Girardeau limestone, calling the whole sequence the Alexandrian series.

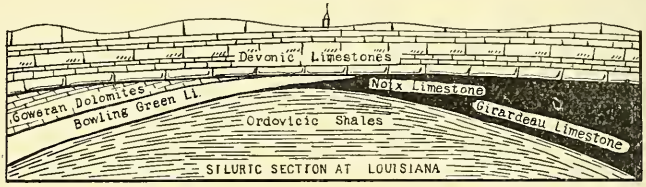
In the proposal of the term Edgewood formation for the three beds—the Bowling Green limestone, the Noix oölite, or local phase of the member later called the Noix limestone by Ulrich,§ and the lower normal limestone to which the title Cyrene was given—the existence of the notable plane of unconformity at the base of the Bowling Green limestone was entirely overlooked. It now transpires that the stratigraphic affinities of the last mentioned formation are with the more northern, or Iowa, section, instead of the more southern, or southern Missouri, section; and that its true relations are with Mid-Silurian rather than with Early Silurian terranes. In consequence of these facts Edgewood Formation as a terranal designation becomes at once invalidated. By slight change in the original signification the term Noix, as applied to a limestone member, assumes a useful and valid rôle. The appellation Cyrene limestone also becomes unnecessary.

Notwithstanding the fact that as originally proposed‖ Alexandrian series is manifestly intended to include strata belong-

* Bull. Geol. Soc. America, vol. iii, p. 286, 1892.
† This Journal, (3), vol. xliv, p. 448, 1892.
‡ Bull. Geol. Soc. America, vol. xxiv, p. 351, 1913.
§ Bull. Geol. Soc. America, vol. xxii, p. 608, 1911.
‖ This Journal (4), vol. xxv, p. 434, 1908.

ing to two distinct sub-periods and that the latter are separated by a widespread plane of unconformity, there is urgent need of a serial term to specifically designate the early Silurian rocks of the Ozark region. There are strong paleogeographical reasons for distinguishing the earlier transgression from the south from a later invasion from the north—Pike County, Missouri, being a district where there occurred some overlapping. The broader or continental relations are well indicated on Schuchert's maps of the distribution of Silurian rocks.* Instead of attempting to further expand terminology unnecessarily, it seems to be a step in advance to retain if possible a name already in use, modifying its original signification slightly to meet the exigencies occasioned by more recently discovered facts. In this way the interests of geologic nomenclature appear best subserved and the title Alexandrian series becomes perfected as a valid designation.

Fig. 1.



The Early Silurian, or southern, deposition in the region is thus represented by the Alexandrian series; Mid-Silurian, or northern, deposition by the Niagaran series. In Iowa the term Niagaran limestone has been in years past applied, as indicated by Calvin,† to all of the Silurian section, or to the upper main body, or Goweran series, as suggested by Norton,‡ of which the Anamosa dolomite is the chief representative. As now understood,§ the Niagaran series of that state comprises only the lower portion of the local Silurian section, represented by the Sabula, Colesburg, Hartwick and Monticello dolomites.

If the invasion of the Silurian sea from the north was gradual and the vertical movement extensive, it is quite likely that the Bowling Green limestone really represents the deposition of Late Silurian time rather than of the Mid-Silurian period; and that it is to be associated with the Goweran series.‖

The stratigraphic relationships under consideration are best expressed in diagram (fig. 1).

* Bull. Geol. Soc. America, vol. xx, pls. 63 and 67, 1910.
† Iowa Geol. Surv., vol. xvii, p. 192, 1907.
‡ Iowa Geol. Surv., vol. xi, p. 302, 1901.
§ Proc. Iowa Acad. Sci., vol. xix, p. 149, 1913.
‖ Iowa Geol. Surv., vol. xxii, p. 154, 1913.

ART. XIX.—*The Use of Telluric Acid in the Determination of Bromine associated with Chlorine in Haloid Salts;* by F. A. GOOCH and H. ISABELLE COLE.

[Contributions from the Kent Chemical Laboratory of Yale Univ.—cclv.]

THE satisfactory separation of bromine from chlorine by the action of differential oxidizers in solution upon haloid salts of these elements depends upon the realization of several conditions: First, the complete removal of free bromine from the solution; second, thorough action of the oxidizer in setting free bromine, so that hydrobromic acid liberated in the action may not escape unattacked; third, the presence of a suitable reducing agent (best a reduction product of the oxidizer) which is effective in counteracting the tendency of free bromine to act upon hydrochloric acid and water with formation of non-volatile bromic acid; and, fourth, practical inertness toward free bromine on the part of everything finally remaining in solution, so that the solution may be devoid of combined bromine in any form when the operation is at an end. These essential conditions of accuracy in the analytical process have been met with a fair degree of success in a process recently developed in this laboratory,* in which reaction takes place between hydrobromic acid and selenic acid (or a mixture of sodium selenate with sulphuric acid) used as an oxidizing agent. The present paper is the account of an attempt to find conditions under which a similar reaction of telluric acid with hydrobromic acid may be brought to completion (any tendency toward the formation of bromic acid being counteracted by tellurous acid formed in the process and the reverse action of bromine upon the tellurous acid practically prevented by volatilization of the bromine) in accordance with the expression

$$H_2TeO_4 + 2HBr \rightleftharpoons H_2TeO_3 + H_2O + Br_2,$$

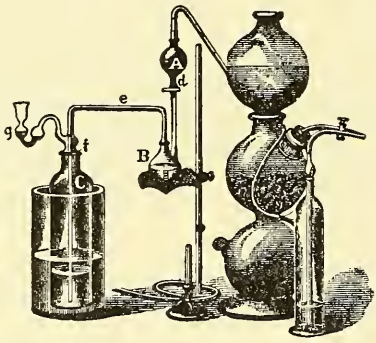
under such conditions that a similar reaction may not take place between telluric acid and hydrochloric acid set free in the reaction.

Unlike selenic acid, telluric acid is not capable, at reasonable concentrations, of ready reaction with bromides to form hydrobromic acid and then free bromine. The function of liberating the hydrobromic acid in order that the telluric acid may play the part of the oxidizer must devolve upon some stronger acid. For this purpose we have made use of sulphuric acid at such dilution that it may not by itself liberate bromine from the bromide with formation of volatile sulphur dioxide. In the

* Gooch and Blumenthal, this Journal (4), xxxv, 54, 1913.

work to be described, telluric acid was prepared by acting with chlorine upon finely divided elementary tellurium suspended in water.* Solutions of iodine and of sodium thiosulphate of approximately N/10 strength were carefully standardized, the iodine against N/10 arsenite and the thiosulphate against the iodine with the use of starch as an indicator. A thiosulphate solution of N/50 strength, for use in the titration of very small amounts of iodine, was prepared by suitably diluting the N/10 solution of that reagent. The potassium bromide used was made by ignition and thorough fusion of potassium bromate specially prepared from purified bromine and potassium hydroxide. The potassium chloride was made by ignition of the pure chlorate. These salts were kept over sulphuric acid in a desiccator and were weighed directly for each determination.

Fig. 1.



The apparatus used for the distillation and absorption of liberated bromine, shown in the accompanying figure, was made with sealed or ground-glass joints throughout by sealing a separating funnel A to a Voit flask B, the outlet tube *e* of the latter to the inlet tube *f* of a Drechsel wash-bottle C, and the outlet tube of the last to a bulbed trap *g*. The Voit flask, which served as the distillation flask, was graduated with etched lines at 5^{cm^3} intervals, to indicate by the position of the liquid meniscus volumes ranging from 5^{cm^3} to 50^{cm^3}. The Drechsel bottle, with the trap, served as a receiver of the distillate, and this was kept cool by immersion in ice-water. A Kipp generator for the delivery of washed carbon dioxide was connected, as needed, with the separating funnel.

In the following tests, the alkali halides and the telluric acid were introduced in solution into the graduated flask and the

* Browning and Minnig, this Journal (4), xxxvi, 72, 1913.

volume was made up with water to 40$^{cm^3}$. The sulphuric acid, 10$^{cm^3}$ of [1 : 1] strength, was added. The connection was made between the flask and the receiver charged with 300$^{cm^3}$ of a 1 per cent solution of potassium iodide, carbon dioxide was passed slowly through the apparatus, and the liquid in the flask, heated gradually at first, was concentrated by boiling to the desired volume.

TABLE I.—*Preliminary Tests.*

	H_2SO_4 [1:1]	10cm^3 :	Initial Volume, 50cm^3-55cm^3.		
H_2TeO_4 taken grm.	KBr taken grm.	KCl taken grm.	Final volume cm^3.	KBr equal to Iodine found grm.	Error in terms of Br. grm.
			A.		
0·5	----	0·1	20	none	none
0·5	----	0·2	20	none	none
0·5	----	0·3	20	none	none
0·5	----	0·4	20	none	none
0·5	----	0·5	20	none	none
1·0	----	0·1	20	none	none
1·0	----	0·2	20	none	none
1·0	----	0·3	20	none	none
1·0	----	0·4	20	none	none
1·0	----	0·5	20	none	none
			B.		
0·5	0·1000	----	20	0·1002	+0·0001
0·5	0·1000	----	20	0·1000	0·0000
0·5	0·1000	----	20	0·1000	0·0000
0·5	0·1000	----	20	0·0999	−0·0001
			C.		
0·5	0·1000	0·1	20	0·0991	−0·0006
0·5	0·1000	0·1	20	0·0996	−0·0003
0·5	0·1000	0·3	20	0·0995	−0·0002
0·5	0·1000	0·3	20	0·0995	−0·0002
0·5	0·2000	0·3	20	0·1996	−0·0003
0·5	0·2000	0·3	20	0·1994	−0·0004
0·5	0·3000	0·3	20	0·2992	−0·0005
			D.		
1·0	0·3000	0·3	20	0·2996	−0·0003
1·0	0·3000	0·3	20	0·2994	−0·0004
1·0	0·4000	0·1	20	0·4000	0·0000
1·0	0·5000	0·1	20	0·4980	−0·0013
1·0	0·5000	0·1	20	0·4986	−0·0010

These preliminary tests showed that (A) in the process of concentrating from a volume of 50$^{cm^3}$ − 55$^{cm^3}$ to a volume of 20$^{cm^3}$ a solution containing 0·5 grm. or 1 grm. of telluric acid with 10$^{cm^3}$ of sulphuric acid [1:1] no chlorine was eliminated from potassium chloride taken in amounts up to 0·5 grm.: that

(B) in the absence of a chloride the bromine was completely eliminated from 0·1 grm. of potassium bromide; but that (C, D) when the chloride was associated with the bromide the evolution of bromine was visibly retarded during the process of boiling and slightly incomplete at the final volume of 20$^{cm^3}$. In the next set of determinations, recorded in Table II, the concentration by boiling was carried still farther.

TABLE II.—*Preliminary Tests.*

	H_2SO_4 [1:1] 10cm^3: Initial Volume, 50cm^3-55cm^3.				
H_2TeO_4 taken grm.	KBr taken grm.	KCl taken grm.	Final volume cm^3.	KBr equal to Iodine found grm.	Error in terms of Br. grm.
			A.		
1·0	----	0·1	15	0·0000	0·0000
1·0	----	0·2	15	0·0000	0·0000
1·0	----	0·3	15	0·0000	0·0000
1·0	----	0·4	15	0·0000	0·0000
1·0	----	0·5	15	0·0000	0·0000
1·0	----	0·1	10	0·0000	0·0000
1·0	----	0·2	10	0·0003	+0·0002
1·0	----	0·3	10	0·0016	+0·0011
1·0	----	0·4	10	0·0042	+0·0028
1·0	----	0·5	10	0·0086	+0·0058
			B.		
1·0	0·1000	0·5	15	0·1000	0·0000
1·0	0·1000	0·5	15	0·1004	+0·0003
1·0	0·4000	0·3	15	0·4002	+0·0001
1·0	0·4000	0·3	15	0·4006	+0·0004
1·0	0·5000	0·2	15	0·5010	+0·0007
			C.		
1·0	0·4000	0·2	10	0·4000	0·0000
1·0	0·4000	0·2	10	0·4000	0·0000
1·0	0·5000	0·1	10	0·5006	+0·0004
1·0	0·5000	0·1	10	0·5003	+0·0002
1·0	0·5000	0·2	10	0·5016	+0·0011
1·0	0·5000	0·2	10	0·5022	+0·0015

From the experiments recorded in A of the table it appears that no chlorine is evolved in the course of concentration to 15$^{cm^3}$ from amounts of potassium chloride up to 0·5 grm.; but that at a volume of 10$^{cm^3}$ chlorine begins to appear appreciably when the potassium chloride amounts to 0·2 grm. From the results of B and C it may be inferred that for solutions containing 10$^{cm^3}$ of sulphuric acid [1:1] and 1 grm. of telluric acid at the outset, concentration to a volume of 15$^{cm^3}$ may be relied upon to remove all the bromine from amounts of potassium bromide up to 0·5 grm.; but there is at the final volume of 15$^{cm^3}$ or 10$^{cm^3}$ an incipient evolution of chlorine which, as was

observed, increases appreciably when the solution is kept hot and allowed to stand.

In the final series of tests, recorded in Table III, the solution (made up similarly to contain 1 grm. of telluric acid, 10^{cm^3} of sulphuric acid [1:1], with amounts of potassium bromide and potassium chloride ranging as high as 0·5 grm. each) was concentrated to a point about midway between the 20^{cm^3} and the 15^{cm^3} marks.

TABLE III.—*Final Tests.*

H_2SO_4 taken cm^3.	H_2TeO_4 taken grm.	KBr taken grm.	KCl taken grm.	Initial volume cm^3.	Final volume cm^3.	KBr equal to Iodine found grm.	Error in terms of Br grm.
			Iodine titrated with N/10 thiosulphate.				
10	1	0·1000	0·4	50	17–18	0·1005	+0·0003
10	1	0·1000	0·4	50	17–18	0·1003	+0·0002
10	1	0·1000	0·4	50	17–18	0·1004	+0·0003
10	1	0·2000	0·3	50	17–18	0·2000	+0·0000
10	1	0·2000	0·3	50	17–18	0·2005	+0·0003
10	1	0·2000	0·3	50	17–18	0·2004	+0·0003
10	1	0·3000	0·2	50	17–18	0·3003	+0·0002
10	1	0·3000	0·2	50	17–18	0·3001	+0·0001
10	1	0·3000	0·2	50	17–18	0·3004	+0·0003
10	1	0·4000	0·1	50	17–18	0·4000	+0·0000
10	1	0·4000	0·1	50	17–18	0·3998	+0·0002
10	1	0.4000	0·1	50	17–18	0·3999	+0·0001
10	1	0·5000	0·5	50	17–18	0·5003	+0·0002
10	1	0·5000	0·5	50	17–18	0·5004	+0·0003
[10	1	0·5000	0·5	50	15	0·5010	+0·0007]
			Iodine titrated with N/50 thiosulphate.				
10	1	0·0025	0·1	50	17–18	0·0025	0·0000
10	1	0 0025	0·1	50	17–18	0·0025	0·0000
10	1	0·0025	0·1	50	17–18	0·0024	−0·0001
10	1	0·0050	0·2	30	17–18	0·0051	0·0000
10	1	0·0050	0·2	30	17–18	0·0050	+0·0001
10	1	0·0050	0·2	30	17–18	0·0052	+0·0002
10	1	0·0050	0·3	30	17–18	0·0053	+0·0002
10	1	0·0050	0·3	30	17–18	0·0051	+0·0001
10	1	0·0050	0·3	30	17–18	0·0052	+0·0002
10	1	0·0050	0·4	50	17–18	0·0052	+0·0002
10	1	0·0050	0·4	50	17–18	0·0055	+0·0002
10	1	0·0050	0·4	50	17–18	0·0057	+0·0005
10	1	0·0055	0·4	50	17–18	0·0055	0·0000
10	1	0·0055	0·4	50	17–18	0·0063	+0·0006

The results of these experiments show clearly that the method may be relied upon to determine with accuracy amounts

of bromine up to 0·3 grm. (0·5 grm. of potassium bromide) associated with 0·25 grm. of chlorine combined in the form of chloride (0·5 grm. of potassium chloride).

According to the procedure found to be effective, the haloid salts are introduced into the Voit distillation flask with 1 grm. of telluric acid. The volume of liquid is made up with water to 40^{cm^3}. The distillation flask and the inlet tube of the receiver, the latter charged with 300^{cm^3} of a 1 per cent solution of potassium iodide, are connected after moistening the surface of the ground-glass joint with sulphuric acid to serve as a lubricant and lute. The sulphuric acid, 10^{cm^3} of the [1:1] mixture, is introduced through the separating funnel. Carbon dioxide is passed very slowly through the apparatus and the reaction mixture is boiled until the meniscus of the liquid is at a level about mid-way between the 20^{cm^3} and the 15^{cm^3} marks, indicating a volume of 17^{cm^3} or 18^{cm^3}. The source of heat is withdrawn and, as soon as the apparatus is cool enough to be handled conveniently, the receiver is disconnected and the free iodine in the receiver and trap is titrated with standard sodium thiosulphate and taken as the measure of the bromine liberated. By the procedure described it is possible to determine with a high degree of accuracy any amount of bromine up to 0·3 grm. when associated in the haloid salts with amounts of chlorine up to 0·25 grm. The entire operation need not occupy more than forty-five minutes.

Art. XX.—*Wilkeite, a New Mineral of the Apatite Group, and Okenite, its Alteration Product, from Southern California;* by Arthur S. Eakle and Austin F. Rogers.

Wilkeite.

Occurrence.—One of the most interesting mineral occurrences of Southern California is situated at Crestmore, about eight miles west of Riverside, in Riverside County, where a contact zone exists between crystalline limestone and granodiorite. The Riverside Portland Cement Company is now quarrying the limestone, with its associated lime silicates, for the manufacture of cement, and the extensive quarrying of the hill of limestone and granodiorite is constantly bringing to view varied and interesting associations of metamorphic minerals.

Much of the limestone is snow-white marble quite free from included minerals other than patches of pure white wollastonite, but on the northeast side of the hill the metamorphism has

been much more intense and localized by the presence of small dikes. This hill is locally designated as the Sky Blue Hill on account of the presence of much beautiful blue calcite, and it is in this blue calcite that the new mineral occurs, as well as an abundance of garnet, vesuvianite and diopside.

Both of the writers visited the quarries during the past summer and one of them (A. S. E.), in company with R. M. Wilke of Palo Alto, made an extensive collection of specimens and has in preparation a paper descriptive of the deposit. One of the minerals collected occurred as an aggregate of pale rose-red grains imbedded in the blue calcite and as it was unrecognized in the field and thought possibly new, much of the mass containing it was collected. Later analyses proved it to be a new mineral and the writers take pleasure in naming it *wilkeite* in honor of R. M. Wilke, who as a mineral collector and dealer has done much to advance the science of mineralogy.

Crystal Form.—Wilkeite crystallizes in the hexagonal system and is prismatic in habit. The largest distinct crystal observed measures 2 mm. by 5 mm. The crystals usually have rounded faces and edges, a very common feature of minerals imbedded in crystalline limestone. Most of them show one or two faces of the prism, and a few were found with a complete hexagonal zone, but the terminal faces are invariably rounded and confused, so that good measurements of the pyramids could not be obtained. Good readings were obtained in the prismatic zone, some of the angles being exactly 60° between the unit prism faces and 30° between $(10\bar{1}0)$ and $(11\bar{2}0)$. A faint image was also obtained for the form $(31\bar{4}0)$. Measured $(10\bar{1}0) : (31\bar{4}0) = 13° 46'$, calculated 13° 54′. The faces of $(11\bar{2}0)$ are very narrow and usually not present on more than two or three of the edges. Some of the terminal faces give good reflections which correspond in position to very steep third order pyramids, but the readings do not correspond to any probable forms. On one crystal a face in the vertical zone with $(10\bar{1}0)$ gave the angle $\rho = 40° 9'$. Assuming this face as the unit pyramid, then the axial ratio for wilkeite is approximately $a : c = 1 : 0{\cdot}730$. This is based on the measurement of a single face and cannot therefore be regarded as the true ratio, but it shows that the axial ratio is at least near that of apatite ($c = 0{\cdot}7346$).

Physical Properties.—Wilkeite has an imperfect basal cleavage and is very brittle. The hardness is about 5. The color is pale rose-red* and varies from sub-transparent to sub-translucent. The luster is sub-resinous on a broken surface, while the prism faces are generally very brilliant. The specific

* A single specimen found later is yellow in color. This is a subhedral crystal about 2 cm. in length. In physical and chemical properties it agrees with the rose-red wilkeite and proves that the color is variable.

gravity, determined with 1·6 gms. of material by means of the pyknometer, is 3·234; at. 20° C.

The index of refraction is 1·640 ± ·005, determined by the Becke test with reference to liquids of known index of refraction. The double refraction is about ·004, determined from the thickness of a thin section by observing the maximum interference color of diopside. The sections give gray and white interference colors of the first order. Basal cleavage plates show a negative uniaxial figure. The elongation of prismatic sections in a slide is parallel to the faster ray. The physical properties as a whole are like those of apatite.

Chemical Properties.—Wilkeite when intensely heated becomes colorless and then assumes a pale bluish green color on cooling. It fuses on its very thin edges, but the fusibility is above 5. It is easily soluble in dilute hydrochloric and nitric acids, leaving flocculent silica, but most of the silica is soluble and can only be removed by complete evaporation. In large fragments or grains gelatinous balls with white opaque centers and translucent exteriors are formed by the acids. In nitric acid, heated nearly to the boiling point, a distinct effervescence is obtained. That the evolved gas is CO_2 was proved by leading it into clear barium hydroxide solution. The wilkeite gives strong reactions for calcium and for the phosphate and sulphate radicals. No test for fluorine or chlorine was obtained. The mineral is practically anhydrous, as hardly more than a trace of water was obtained by heating the powdered mineral in a tube by the Penfield method.

Several analyses of the mineral were made by different methods and with different samples. The results showed that the constituents were constant in amount. The silica was always first removed by two complete evaporations and the amount determined by subsequent treatment with HF and H_2SO_4. The sulphate was determined as $BaSO_4$, and also as $CaSO_4$ by direct precipitation from a slightly acid solution by means of alcohol. The results by alcohol were slightly lower than those obtained with $BaCl_2$ or $Ba(NO_3)_2$.

The calcium was determined in three ways: 1. Indirectly, by successive precipitations as $CaSO_4$, $Ca_3P_2O_8$ and $CaC_2O_4 \cdot 2H_2O$ and combining the calculated amounts of CaO. 2. Directly, by precipitation as $CaSO_4$ by means of H_2SO_4 and alcohol. 3. Directly, by addition of ammonia and then acetic acid to redissolve the calcium phosphate and precipitation as calcium oxalate, this method giving the most accurate results. In the determination of the phosphate considerable difficulty was encountered in getting a complete precipitation by the ordinary molybdate method or by the Woy method, and it was found

that the best results were obtained by its precipitation with magnesia mixture in the solutions remaining after direct precipitations of all calcium. The great excess of calcium in the solution permits of a direct precipitation by ammonia of the phosphorus, as $Ca_3P_2O_8$, and a small amount of manganese phosphate, presumably $Mn_3P_2O_8$. The former goes into solution readily on addition of acetic acid, leaving the manganese phosphate to be weighed as such.

The average of the analyses gave as the composition of wilkeite:

		Molecular ratios.		
CaO	54·44%	0·972	19·66	or 20
MnO	0·77	0·011		
P_2O_5	20·85	0·147	2·94	3
SO_3	12·28	0·157	3·14	3
SiO_2	9·62	0·160	3·20	3
CO_2	2·10	0·048	0·96	1
H_2O	trace			
	100·06			

The molecular ratios indicate that the chemical formula of wilkeite is $20CaO.3P_2O_5.3SiO_2.3SO_3.CO_2$, which may be written $3Ca_3(PO_4)_2.3Ca_2SiO_4.3CaSO_4.CaCO_3.CaO$.

Relation to Apatite.—The physical properties suggest that wilkeite belongs to the apatite group, but it contains only 20 per cent P_2O_5 as against 41 or 42 per cent for apatite. The formula may be written $3Ca_3(PO_4)_2.CaCO_3.3Ca_3[(SiO_4)(SO_4)]$. CaO, which shows its relation to the apatite group. In wilkeite the compound radical $[(SiO_4)(SO_4)]^{vi}$ is equivalent to $(P_2O_8)^{vi}$. The replacement of fluorine in the formula $3Ca_3(PO_4)_2.CaF_2$ by oxygen, O, or by the carbonate radical, CO_3, may be explained by mass-effect isomorphism; but the replacement of $(PO_4)_2$ by the compound radical $[(SiO_4)(SO_4)]$ is explained by the fact that they have nearly the same formula weights, 190 and 188·4, respectively, and the same valence (six). Wilkeite has a molecular volume almost identical with that of apatite, and this explains why compound molecules, which are so dissimilar chemically, may form isomorphous mixtures. Whether wilkeite is an isomorphous mixture of $3Ca_3(PO_4)_2.CaCO_3$ and $3Ca_3[(SiO_4)(SO_4)].CaO$ or $3Ca_3(PO_4)_2.CaO$ and $3Ca_3[(SiO_4)(SO_4)].CaCO_3$ or a double salt of these two compounds, it is impossible to say. The ratios are fairly close to $Ca_3(PO_4)_2 : Ca_2SiO_4 : CaSO_4 = 1:1:1$, but this agreement may be accidental.

There are a number of minerals with three radicals, such as hanksite, $9Na_2SO_4.2Mg_2CO_3.KCl$, sulfohalite, $2Na_2SO_4.NaCl$.

NaF, northupite, $MgCO_3.Na_2CO_3.NaCl$, tychite, $2MgCO_3.2Na_2CO_3.Na_2SO_4$ and thaumasite, $CaSiO_3.CaCO_3.CaSO_4.15H_2O$, but as far as we know wilkeite is the only mineral with four acid radicals.

Summary of the properties of wilkeite.—Hexagonal, $c = 0{\cdot}730$ approximately. Forms $(10\bar{1}0)$, $(11\bar{2}0)$, $(10\bar{1}1)$, cleavage imperfect basal. H = 5. G = 3·234. Color pale rose-red. Uniaxial, optically negative. $n = 1{\cdot}640 \pm {\cdot}005$. $(n_1 - n) = 0{\cdot}004$. Fusibility = $5\frac{1}{2}$. Soluble in dilute hydrochloric and nitric acids with the separation of flocculent silica. Gives wet tests for sulphate and phosphate radicals and for calcium.

Chemical formula: $3Ca_3(PO_4)_2.CaCO_3 + 3Ca_3[(SiO_4)(SO_4)].CaO$.

Occurrence.—In a crystalline limestone contact zone, associated with diopside and vesuvianite.

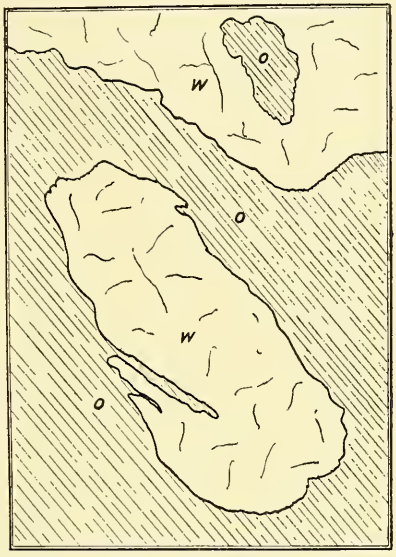
Okenite.

Properties.—The wilkeite is often altered to a white opaque mineral with a pearly luster and fibrous structure. This mineral was identified as okenite by its optical properties. The index of refraction determined by the Becke test with reference to liquids of known index of refraction is $1{\cdot}565 \pm {\cdot}005$. The double refraction determined by the maximum interference color in a thin section of known thickness is ·009 or ·010. Only a very few minerals have this combination of optical characters* and of these okenite is the only one that agrees at all in chemical properties. The okenite is easily fusible to a glass and gives abundant water in the closed tube. In thin sections the mineral is translucent and shows a fibrous aggregate structure with parallel extinction and elongation parallel to the slower ray. The relief is low compared with wilkeite. All stages in the alteration of the wilkeite to okenite can be observed, from wilkeite with a narrow border of okenite to specimens of okenite with minute remnants of wilkeite. Several distinct pseudomorphs of okenite after wilkeite were noted.

The accompanying figure is a camera lucida sketch of the wilkeite in process of alteration to okenite. The okenite is the fibrous mineral with low relief. The two parts of the wilkeite are in optical continuity. The penetration of the wilkeite by okenite stringers and the ragged edges of the wilkeite makes it certain that the okenite is an alteration product of the wilkeite. The other minerals associated with the wilkeite show no evidence of alteration. Wollastonite

* See Table of Refringence and Birefringence in the back of Winchell's Elements of Mineralogy.

occurs in a few of the specimens which contain the okenite but they have no apparent relation to each other, although of the same general composition. The okenite was also found by D. P. Carlton of Riverside rather uniformly distributed through a blue crystalline limestone containing small crystals of diopside and vesuvianite. The okenite occurs in opaque white subhedral crystals from 1 to 3 mm. in size. A thin



Wilkeite (*W*) altering to okenite (*O*). (50), Crestmore, Riverside Co., California.

section of this okenite-bearing limestone shows a few minute remnants of wilkeite from which the okenite has conclusively altered.

It was found to be practically impossible to separate the okenite from the wilkeite and a quantitative analysis of the substance indicated that it was a mixture of the two. There was a loss of sulphate and of lime and a large increase in the silica with the additions of about 10% of water.

The change of wilkeite to okenite was probably brought about by magmatic waters, for it is not due to ordinary weathering.

(A. S. E.) University of California, Berkeley, California.

(A. F. R.) Stanford University, California.

Art. XXI.—*The Rocks of the Cerro de Santa Ana on Paraguana, Venezuela;* by T. A. Bendrat.*

During the course of a journey in Venezuela in the summer and fall of 1912 the writer had an opportunity of visiting and studying the rocks of the peninsula of Paraguana. As a result, he offers the following notes as a contribution to the geology of this little known region and has supplemented them by a petrographic description of the rocks collected at this time.

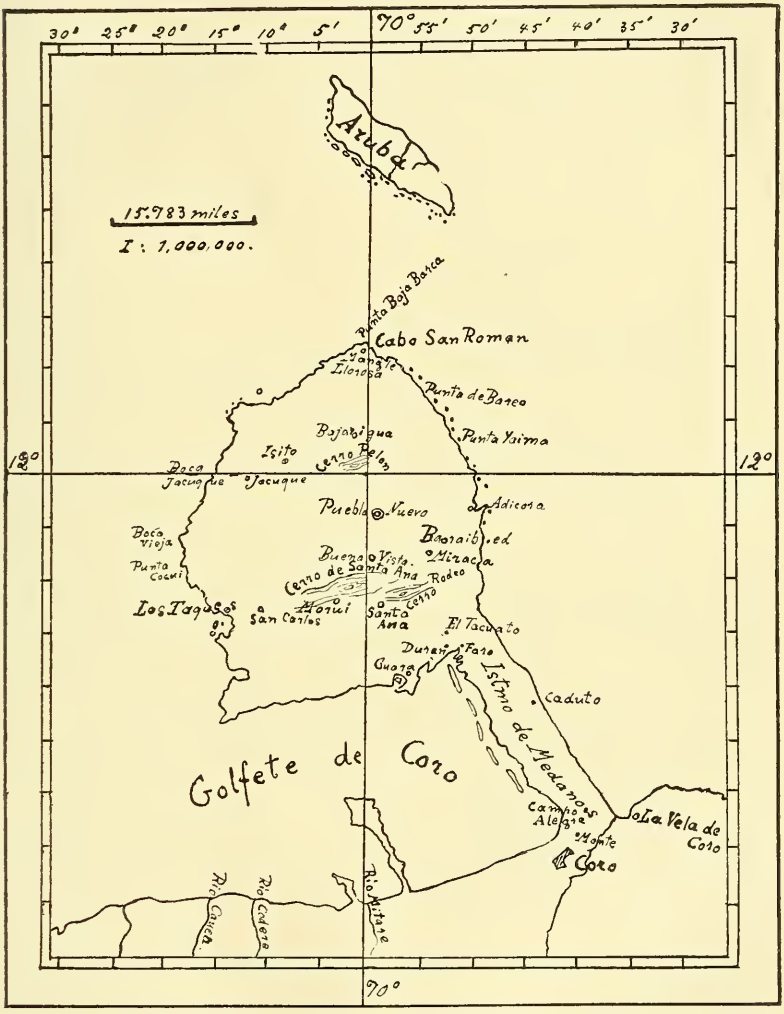
The geology of the peninsula differs in an important respect from that of the mainland immediately to the south, and of the neighboring islands, in that it contains exposed areas of the granites, gneisses and schists which constitute the foundation of the peninsula, while they are covered with Cretaceous and later sedimentary deposits. It should be noted, however, that the Cretaceous and Tertiary deposits occur also on Paraguana along with the rocks previously mentioned. In Paraguana the basal complex of granites, gneisses and schists has been invaded, probably in pre-Cretaceous times, by intrusive masses belonging to the diorite and gabbro families. These form the most prominent elevations of the region and around them have been deposited a Cretaceous series: sandstones and limestones. Among the latter are beds carrying *Rudistæ*. These rocks after long-continued erosion were folded in Tertiary times, probably before the later Miocene. During the latter part of the Tertiary other sediments, which now form by far the greatest part of the exposed rocks of the peninsula, were deposited around the intrusive masses, as well as the remnants of the disturbed Cretaceous beds, and are found to merge without apparent break into Quaternary strata.

The Cerro de Santa Ana is the highest elevation in Paraguana and was ascended by the writer under circumstances of great difficulty, and its geology studied. The base of this mountain strikes in a general WSW. and ENE. direction, nearly parallel to the north and south coasts of the peninsula; in breadth it is about 4 kilometers. In the opinion of the writer this mass represents an exposed laccolith composed entirely of basic rocks, weathering a tan-brown in color and of a slate gray on a freshly broken surface. In the lower portion it is a fine-grained diabase, which the writer, ascending the mountain from the west, traced up to an altitude of 1050 feet with certainty, and at 1275 feet it was found to give way to a rock

* The writer desires to express his obligations to Professor N. M. Fenneman, head of the department of geology of the University of Cincinnati, Ohio, who most generously placed the apparatus and facilities of the department at his disposal.

which is here designated as hornblende porphyry. On the north side, however, W. Sievers states that the transition to the porphyry occurs at an elevation of 450 feet. This horn-

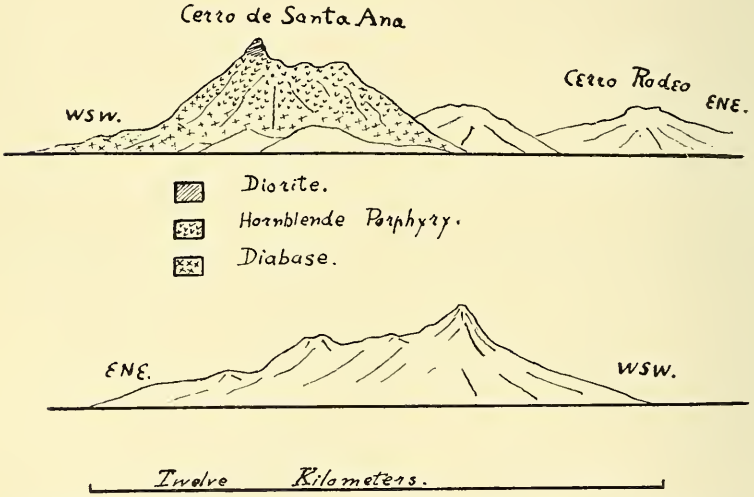
Fig. 1.



blende-porphyry, which weathers a brownish color, towers more or less abruptly in bold cliffs up from the base of diabase, here and there interrupted by short shoulders. It is considered by the writer an intrusion into the diabase under such circumstances as favored the formation of a porphyritic texture. This por-

phyry was traced to an elevation of 2550 feet to the foot of the last steep cliff. At this point the mountain culminates in a pinnacle or "horn," as may be seen in the accompanying figures, and attains a height of 2975 feet above sea-level. The pinnacle is composed of a different rock from the porphyry below, in that it is a hornblende diorite of fine to medium-grained texture without phenocrysts, which weathers to a dark chocolate-brown, and exhibits on freshly broken surfaces a bluish gray color, and is penetrated by an intricate system of veinlets. It has a very uneven fracture which makes the pinnacle extremely rugged, and its ascent very difficult. On

FIG. 2.



FIGS. 1, 2. The diagrams of figs. 1 and 2 were taken with Dr. W. Sievers' permission from the latter's work: "Zweite Reise in Venezuela, 1892-93"; the geology has been introduced by the writer.

account of its different texture the writer is inclined to believe that it is a still younger intrusive which invaded both the diabase and the hornblende porphyry.

PETROGRAPHY.

Diabase.—This is an aphanitic rock which in thin section under the microscope is seen to be composed of augite, olivine and plagioclase and is holocrystalline. Of the minerals plagioclase is predominant, olivine less so, while the amount of augite is relatively small. The section shows an even, granular groundmass of these three minerals, in which occur, scattered larger, more or less allotriomorphic crystals of plagioclase.

From measurements of extinction angles it is inferred that the plagioclase of the groundmass and also of the larger crystals is anorthite. The pyroxene is a variety of augite which exhibits a faint pleochroism. The olivine, which is well distributed throughout the rock, is also occasionally in allotriomorphic forms but for the most part exhibits crystal outlines. It contains black inclusions of iron ore, mostly along cleavage cracks, and this occurs also at times in the augite.

The rock appears to have undergone crushing through dynamic processes, as shown by the crushed and broken condition in which many of the feldspar and olivine crystals are found. The augite granules and shreds are also drawn out into more or less wavy trains which maintain a certain degree of parallelism. There are also different systems of veinlets crossing the rock which are made up of angular grains of olivine and predominant feldspar. Three systems of these veinlets were observed and they were frequently found to interfere with one another, exhibiting thrusts and miniature faults. Such faults are found also in the larger feldspar crystals which, moreover, these veinlets penetrate.

Hornblende-porphyry.—This rock has a phanerocrystalline, evenly granular groundmass of feldspar and amphibole in which are scattered formless crystals of green hornblende with an occasional one of feldspar. Under the microscope it is seen that the larger hornblendes are to some extent altered, their green color fading in places and at their margins passing over into fibrous actinolite. The larger feldspars are mostly of plagioclase, but sometimes microcline. Like the diabase previously described, this rock appears to have suffered from dynamic processes as shown by the bent condition of the cleavage cracks in the crystals of hornblende and by faults across them. The plagioclase shows similar features; like the former rock, the mass is penetrated by a series of veinlets of a feldspathic nature.

Hornblende-diorite.—Unlike the foregoing types, this rock is macrocrystalline in that its constituents can be determined by the eye. The chief components are hornblende and plagioclase, the latter varying in composition from labradorite to anorthite.

The hornblende in section varies in color from light green to brown even in the same section and in some places it is altered to a colorless variety. It contains inclusions of magnetite and of hematite, the latter being regarded as an alteration product. The plagioclases are twinned according to both the Carlsbad and albite laws. Decomposition of the feldspar is shown in places by its dull and cloudy aspect. It sometimes shows inclusions of apatite needles. The fabric of the rock is somewhat ophitic in that

lath-shaped, almost automorphic crystals of the feldspar are frequently found projecting into the larger, formless crystals of hornblende. Both the feldspars and the hornblendes have apparently suffered much crushing and breaking, due to the operation of dynamic forces, and like the types previously described, the rock is penetrated by an intricate network of delicate veinlets. The olivine however, which occurs in the diabase, is wanting in this rock.

Sandstone.—This occurs at the base of the mountain described in the foregoing part of this paper. It is seen in thin beds, slightly upturned toward the north and northeast and also as debris in the arroyo issuing from the west slope, where it is mingled with that of the diabase forming the base of the mountain. It is a fine-grained, firm, reddish brown variety of sandstone which is rich in muscovite.

Studied in thin section, it is seen that the grains of quartz, which is the chief component, are sharply angular and not rounded like those met with in ordinary sandstones. Also, they seldom appear to be in direct contact but are held together by an interstitial cement in the form of nodular oolitic grains. The quartzes have an undulatory extinction, indicating that they were once components of some rock which suffered dynamic processes. They are clouded with extremly fine particles arranged in trains, which may be of magnetite, and in some cases also needles of rutile. The muscovite occurs in notched and jagged scales whose parallel arrangement is due to sedimentation. It is more or less altered and associated with some chlorite. Brown amphibole, plagioclase feldspar of several varieties and microcline were also found in the rock. The chemical test of the nodular oolitic cement, which was kindly made for me by Dr. D. H. Neuland, proves it to consist of siderite; and it is considered by him to be a later infiltration product. This makes the sandstone in question of interest, as in most oolitic iron ores, according to Dr. Neuland, the oolites enclose the quartz, as for instance in the Clinton iron ores.

Spades, Ripley Co., Indiana, Dec. 1913.

SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *The Rusting of Iron in Water.*—W. A. Bradbury has made some interesting experiments upon this subject. He found that when bright iron wire was placed in Manchester tap-water it soon became coated with rust and the water gave a blue color with potassium ferrocyanide. When the water was well boiled and the flasks were corked no rust appeared on the wire. When water containing wire was exposed to an enclosed volume of air, one-fifth of the air, corresponding to the oxygen in it, was gradually absorbed, and the water showed the presence of ferrous iron in solution. No hydrogen could be collected when the wire was rusted by the ordinary water in a flask containing a delivery tube. However, when carbon dioxide was passed into the water for a short time it did not cause rusting, but iron went into solution, probably according to the reaction,

$$Fe + 2H_2CO_3 = H_2Fe(CO_3)_2 + H_2,$$

but no hydrogen appeared at first, apparently on account of the oxidation of the nascent hydrogen by the oxygen present. Then after a few days hydrogen began to be liberated and much iron went into solution without any rusting of the wire. The effect of the presence of a large amount of magnesium chloride in the water kept near its boiling point upon iron wire in absence of air was tried. No rust or gas were produced, nor did any iron go into solution. It appears, therefore, that the prevailing opinion that magnesium chloride has a corrosive action upon iron is incorrect.— *Chem. News*, cviii, 307. H. L. W.

2. *The Estimation of Periodates in the Presence of Iodates and Iodides.*—It has been found by Müller and Friedberger that iodates do not react with iodides in sodium bicarbonate solutions, but that periodates are reduced to iodates under these circumstances with a liberation of iodine corresponding to one-quarter of the oxygen of the periodate. Müller and Wegelin state that it is a long operation to change alkaline carbonates or hydroxides into bicarbonates by means of carbon dioxide in order to carry out the titration, while strong acids cannot be used for the purpose, as they bring about the reaction of the iodate and iodide in the part of the solution where the acid flows in. They have found, however, that boric acid in the presence of borax may be used for the acidification of such solutions, and that the reaction then takes place precisely in the same way as in the presence of bicarbonates. They recommend the titration of the free iodine by means of arsenious acid. The iodate may then be determined by adding potassium iodide, acidifying with sulphuric acid, adding saturated borax solution until congo-red

paper no longer turns blue, and titrating again with arsenious acid. The test analyses show perfectly accurate results.—*Zeitschr. analyt. Chem.*, lii, 755. H. L. W.

3. *A Dictionary of Applied Chemistry;* by Sir Edward Thorpe, Assisted by eminent Contributors. Revised and Enlarged Edition in Five Volumes. Vol. V. 8vo, pp. 830. London, 1913 (Longmans, Green and Co. Price, $13.50 net per volume).—It is a matter of satisfaction to notice that the publication of this great work of reference has been completed within two calendar years, so that the whole work, of recent date, is now available for use. There is no doubt that this dictionary is of the greatest importance and value, and that it is essential to the equipment of all libraries where reference to chemical topics is demanded. The present volume contains many interesting articles, such as those on sodium, spectrum analysis, starch, sugar, sulphur, sulphuric acid, synthetic drugs, tannins, vegeto-alkaloids, water, destructive distillation of wood, and many others. The modern treatment of the subjects is illustrated by an excellent account, under sulphur, of the Trasch method of mining this substance as practiced in Louisiana, and in general, throughout the whole work, the topics appear to be ably treated from the most recent point of view. H. L. W.

4. *Allen's Commercial Organic Analysis;* Fourth Edition, entirely rewritten, edited by W. A. Davis and Samuel S. Sadtler. Vol. VIII. 8vo, pp. 696. Philadelphia, 1913 (P. Blakiston's Son & Co. Price $5.00 net).—This is the last volume of this important work, but it is proposed to issue at a later date a supplementary volume containing a complete reference index of the whole work, and including also such additions as are needed to bring the work up to date.

The present volume deals with enzymes, proteins and albuminoid substances, milk and milk products, meat and meat products, hæmoglobin and blood, proteoids, fibroids. This volume contains much valuable information for those who are interested in the chemistry of foods, and the whole work is a most important and useful addition to the literature of industrial analysis.

H. L. W.

5. *Chemistry, Inorganic and Organic;* by Charles Loudon Bloxam. Tenth Edition, rewritten and revised by Arthur G. Bloxam and S. Judd Lewis. Large 8vo, pp. 878. Philadelphia, 1913 (P. Blakiston's Son & Co. Price $5.00 net).—The first edition of this work appeared in 1867. The editors of the present edition have endeavored to maintain the reputation of the book as the most compendious work on chemistry in a single volume, and it appears that they have very successfully carried out this aim. The book is intended for students of chemistry as well as for those professionally interested in the science. It gives a very full account of modern chemical facts and theories, and it describes and illustrates many important experiments. It is extensive enough to serve well as a book of reference in con-

nection with ordinary chemical topics, and in general it is an excellent and useful book. H. L. W.

6. *Quantitative Chemical Analysis;* by Clowes and Coleman. 8vo, pp. 577. Philadelphia, 1914 (P. Blakiston's Son & Co. Price, $3.50 net).—This is the tenth edition of a well-known and widely-used text-book, which discusses general processes, gives courses in simple gravimetric estimations and in volumetric analysis, and gives an extensive treatment of many kinds of industrial analysis, including the examination of ores, alloys, fuels, silicates, water, foods, soaps, oils, gases, etc. Ultimate organic analysis and molecular weight determination are treated also. Besides a revision of the text, several important additions have been made in the form of an appendix. H. L. W.

7. *Industrial Organic Analysis;* by Paul S. Arup. 12mo, pp. 340. Philadelphia, 1913 (P. Blakiston's Son & Co.).—This book is intended for the use of advanced students in chemistry, giving them some insight into methods of industrial analysis. The materials included within the scope of the volume are coal and coke, coal tar and its distillation products, fats and oils, soap, petroleum products, milk and butter, starch and its products, and food preservatives and colors. A list of references is appended to each chapter. The point of view is English, which rather detracts from the value of the book for American students' use. A. L. D.

8. *The Radioactive Origin of the Color of Zircons.*—Some interesting properties of the zircons are discussed in a very recent paper by the Hon. R. J. Strutt. The communication deals only with the brown crystals of which two kinds may be distinguished: the common opaque brown variety which occurs in Norway and North Carolina, and the transparent reddish brown kinds known as "hyacinth" which may be obtained, for instance, from Expailly in Auvergne, from Unkel on the Rhine, and from Campbell Island, New Zealand. It is a noteworthy fact that the opaque variety occurs in plutonic rocks, such as syenites, and the transparent only in basalts and other lavas. Furthermore hyacinths lose their reddish brown color completely when heated to a temperature of about 300° C. Since zircon strongly resists chemical attack the question at once arises as to how this mineral acquired its color, when the high temperature of its original matrix is taken into account. Again, the transparent zircons are thermoluminescent. These crystals, when moderately heated, give out a phosphorescent glow and simultaneously lose their tint. Also this glow does not recur on subsequent heating of the same specimen. Hence the query: How has the capacity of native unheated crystals to glow been recovered?—for presumably it was not possessed by the crystals when they first cooled down in the molten lava.

The keynote to the explanation of the apparent difficulties just suggested is given by the fact that crystals decolorized by heat have their color restored by exposure to the radiations from

radium. One day's exposure to a few milligrams of radium produces a distinct effect in restoring the color. At the same time the property of thermoluminescence is acquired. Moreover Strutt showed, in the year 1906, that zircon is a distinctly radioactive mineral, containing hundreds of times as much radioactive matter as ordinary rock masses. He therefore advances the hypothesis that "*the zircons found in lavas have had their colour and thermoluminescence restored by the slow action, during prolonged ages, of the radium they themselves contain.*" Unfortunately the color of fresh crystals is saturated, that is, further exposure to radioactive matter does not deepen it. Consequently, it is not possible to determine the age of hyacinths from the rate of coloration and the amount of radioactive material present. Experiments were performed to test this point and it was found that the original saturated tint was imparted to a specimen which had been decolorized by heating and then exposed for four days to the radiations from a radium salt.

On the other hand, the opaque brown zircons, as originally found, are not thermoluminescent and they cannot be made so by exposure to radium. Furthermore they do not lose their color when moderately heated. Since there are reasons for believing that hyacinths are formed from these opaque zircons by the action of a bath of molten basalt, an attempt was made to imitate this process experimentally. Basalt was kept melted in a platinum crucible over a gas furnace and some opaque zircons were immersed in the molten mass for 24 hours. After this they were extracted and found to be quite white, though not transparent. On exposure to radium they assumed the redder tint of hyacinths and became thermoluminescent. In conclusion Strutt says: "The only outstanding point is the transparency of natural hyacinths." "This may result in some way from the gently increasing, very prolonged action of the molten basalt under geological conditions, which cannot be artifically imitated."—*Proc. Roy. Soc.*, vol. lxxxix (A), p. 405. H. S. U.

9. *Suppression of the Photoelectric Effect.*—A great step in advance seems to have been made by the theoretical considerations and experimental skill of K. Fredenhagen and Hans Küstner. For lack of space a description of the apparatus used and an account of the extraordinary refinement of the method will not be given. The experimental data refer only to zinc, since the investigation of other metallic surfaces is still in progress. The results obtained may be summarized as follows :

(1) No measurable photoelectric effect can be obtained with pure zinc surfaces when all traces of reactive gases have been removed. That is, the photoelectric effect is less than one thousandth part of the value found under ordinary experimental conditions.

(2) The "fatigue" which occurs in the presence of reactive gases can be accounted for by the reaction with adsorbed gases. The "recovery" is explained by the diffusion of reactive gases towards the zinc, whereby the velocity of the reaction and consequently

the strength of the photoelectric current are conditioned by the concentration of the reactive gases at the zinc surface. The time variation of the photoelectric current can be changed multifariously by suitable combinations of the two processes constituting fatigue and recovery.

(3) So long as ionization by collision does not enter as a factor, the pressure of neutral gases has no influence on the magnitude of the photoelectric effect.—*Physik. Zeitschr.*, No. 2, Feb., 1914, pp. 65, 68. H. S. U.

10. *The Effect of Temperature on X-ray Diffraction Patterns.*—DeBroglie immersed a cubical crystal of rock salt in liquid nitrogen during an entire exposure with Röntgen rays and obtained a photographic negative which was sensibly the same as had been previously gotten with the same crystal at the ordinary room temperature. In other words, the number, relative position, and sharpness of the images appeared to be the same at both temperatures. The same investigator tested a crystal of tourmaline at a bright red heat and at the temperature of liquid air. The only variation shown by the negatives *seemed* to be a very slight decrease in intensity of the photographic impressions corresponding to the higher temperature.

These results are in accord with the mathematical analysis of P. Debije. It also comes out from this theory that as the temperature of a crystal is raised the points close to the central image are less influenced than the more remote images. Since the work of de Broglie on the sharpness of the points at different temperatures needed verification, the problem has been taken up anew by M. v. Laue and J. Steph. van der Lingen. The experimental method consisted essentially in passing X-rays from the same bulb simultaneously through two specimens taken from the same crystal. Both pieces were subjected to as nearly identical conditions as possible in all respects save one, namely, the one crystalline fragment was heated in an electric oven while the other was either kept at room temperature or plunged in liquid air. Rock salt and mica were investigated from 320° C. and 400° C. respectively down to −190° C. The authors conclude from their work that, at least qualitatively, the theory of Debije on the influence of temperature is verified.—*Le Radium*, June, 1913, p. 186; *Physik. Zeitschr.*, No. 2, p. 75, 1914. H. S. U.

11. *A Method of Measuring the Pressure Produced in the Detonation of High Explosives or by the Impact of Bullets.*—Some interesting and instructive data relative to the preceding title have been recently obtained by Bertram Hopkinson. The apparatus used may be briefly described as follows: A cylindrical steel rod is suspended after the fashion of a ballistic pendulum. To one end of this rod a short segment of the same specimen of steel and having the same cross-section is caused to adhere by magnetic attraction. The ends of the rods which are in contact have to be accurately plane and smooth. Beyond the short end-piece an ordinary ballistic pendulum is hung up so as to catch the

end-piece when it flies off from the longer steel rod. With this assemblage of apparatus it is easy to determine the momenta of the steel rod and of its extension after an impulsive force has been applied to the end of the rod (the free end) which is more remote from the auxiliary ballistic pendulum.

The following outline of the elementary theory of the action of the steel rods may not be superfluous. When a rifle bullet is fired against the end of a steel rod, or when some gun-cotton is detonated near this end, a wave of pressure is propagated along the rod with the speed of sound in steel. This compressional wave travels practically unchanged across the plane of contact of the rod and its end-piece, provided the pieces of metal are in good, firm contact. At the free end of the shorter rod the disturbance is reflected as a wave of tension, and hence the pressure at any cross-section is obtained by adding the effects of the pressure and tension waves. At the interface of the rods the pressure persists until the head of the tension wave arrives there. If the tail of the pressure wave has then passed the joint the end-piece flies off, having trapped within it the whole of the momentum of the blow, and the longer rod is left completely at rest. The length of end-piece which is just sufficient to entirely stop the main rod is equal to half the length of the compressional wave, and the duration of the blow is twice the time taken by this wave to travel the length of the steel extension. Further, it can be proved that the momentum trapped in very short end-pieces will be equal to the maximum pressure multiplied by twice the time taken by the wave in traversing the end-piece. Thus by experimenting with different lengths of end-pieces and determining the momentum with which each flies off the rod as a result of the blow, it is possible to measure both the duration of the blow and the maximum pressure developed by it.

The method was first tested by firing lead projectiles against the free end of the steel-rod pendulum. With speeds of 700, 1240, and 2000 feet per second the observed "maximum pressures" were found to be 5320, 16700, and 42600 "lb." respectively. The corresponding calculated values are given as 5450, 15700, and 43500 "lb." The computations are based on the assumption that a lead bullet behaves on impact as a fluid. It then follows that the time required to completely stop the bullet, which is the duration of the blow, is equal to the time taken by the projectile to travel its own length, and also that the maximum pressure is equal to the mass per unit length in the section of greatest area multiplied by the square of the speed. In the case of the highest speed used the observed duration of the blow is about 6 per cent. greater than the time taken by the missile to travel its own length. This discrepancy can be accounted for on the ground that the conditions postulated in the simple theory are not entirely fulfilled by the experimental tests. For example, the lead does not act as a perfect fluid, and the pressure exerted by the bullet is not uniformly distributed over the end. Experi-

ments with rods of different diameter showed that the larger ones give higher values for the estimates of the duration of impact.

Having thus satisfied himself that the experimental method gives approximately correct results, Hopkinson next performed some similar experiments on gun-cotton. Cylinders of dry gun-cotton 1·25 in. × 1·25 in. and weighing about 1 oz., were detonated with fulminate at a distance of about 0·75 in. from the end of the steel rod. The average value of the pressure during an interval of 10^{-5} secs., in the neighborhood of the maximum, was found to be about 30 tons per square inch. The absolute maximum is of course considerably higher. The pressure had practically disappeared in 1/50,000 sec., so that at least 80 per cent. of the impulse of the blow had been delivered within that time. When the gun-cotton was exploded in contact with the rod the blow was deadened by the deformation of the steel. Nevertheless, the conclusion was reached that the maximum pressure at the surface of contact is at least double what it is when an air gap of 0·75 in. is interposed. The results obtained for gun-cotton throw some light on the nature of the fracture which is produced by the detonation of this explosive in contact with a mild steel plate. The effect of the explosion is to give speed to the parts of the plate with which the gun-cotton was in contact, the remainder being left at rest. For example, in a plate 1 inch thick the speed imparted by a slab of gun-cotton of about the same thickness is roughly 200 feet per second. In *static* tests on mild steel the metal flows when the shearing stress is of the order of 10 tons per square inch, and no materially greater stress can exist. On the other hand, if the rate of straining is sufficient, the viscosity of the flowing metal becomes important, and the shearing stress may approximate to the value corresponding to perfect elasticity. Assuming this condition to be fulfilled in the case of the mild steel plate 1 inch thick, shearing stresses of the order of 100 tons per square inch may be produced. The shearing stress is accompanied by tension which may be sufficient, under the given conditions, to overcome the forces of cohesion. Thus the steel is cracked in spite of its ductility, just as cool pitch may be broken by the blow of a hammer. From the measured duration of the pressure produced by gun-cotton it may be inferred that the speed of shear necessary to fracture mild steel is of the order of 1000 radians per second. The shattering of the plate probably occurs within two or three hundred-thousandths of a second, that is, while the pressure is acting and before appreciable deformation has had time to set in. The observed bending of the steel fragments occurs subsequently and is due to the relative velocities which remain in the different parts of each piece of the plate after the plate has been broken and the pressure has ceased to act.—*Proc. Roy. Soc.*, vol. lxxxix (A), p. 411. H. S. U.

II. Geology and Natural History.

1. *Thirty-fourth Annual Report of the Director of the United States Geological Survey*, George Otis Smith, *to the Secretary of the Interior, for the fiscal year ended June 30, 1913.* Pp. 183, 2 maps.—During the fiscal year 1912–13, geologic field work was carried on in 45 states and Alaska. Topographic mapping was continued in 26 states, in addition to Alaska and Hawaii, and underground water investigations were prosecuted in 19 states. This field work involved 378 members of the regular Survey staff, besides an even larger number of temporary assistants. The publications for the year include 1 Monograph, 5 Professional Papers, 28 Bulletins, 25 Water-supply Papers, 4 Geologic Folios, and 102 topographic maps. Noteworthy features of the geologic work are the increased attention to coastal plain geology, and the lack of recognition of physiography. The report of the Chief Geographer shows that 38·9 per cent of the United States has been covered by topographic maps. The Land Classification Board, with a personnel of 35, has amply demonstrated its usefulness as scientific adviser to the government in matters relating to the public domain. The public's interest in natural resources is protected, titles are secured more promptly, and large sums formerly expended for field investigation by the Indian Office and the Land Office are saved to the public treasury. The contribution of the Survey to educational and economic needs is indicated by the fact that during the year 1912–13, 375,213 books, 46,387 folios, and 648,373 maps were distributed.

It is discouraging to note that in the face of increased demands on the Survey's time and funds, and the increased value of the organization as an economic and educational factor, the appropriation for 1913 was less than that for 1912, and that out of a total of $1,497,920, only $236,000 was available for geologic work. The volume and quality of work has been maintained only by exercising rigid economy, by working overtime, cutting out leave of absence and sick leave. The organization is evidently undermanned and under-equipped. The Survey force is also underpaid, with the natural result that 41 geologists have left the service since July, 1909, and have obtained an average immediate financial gain of 149 per cent. H. E. G.

2. *Publications of the United States Geological Survey.*—Recent publications of the U. S. Geological Survey are noted in the following list (continued from vol. xxxvi, pp. 424, 425):

Folios.—No. 185. Murphysboro-Herrin Folio, Illinois; by E. W. Shaw and T. E. Savage. In coöperation with the Geological Survey of Illinois. Pp. 15; 3 colored maps, giving topography and geology, 13 figs.

No. 187. Ellijay Folio, Georgia–North Carolina—Tennessee; by Laurence La Forge and W. C. Phalen. Pp. 17; 4 colored maps, topography and geology, 7 figs.

No. 188. Tallula–Springfield Folio, Illinois; by E. W. Shaw and T. E. Savage. Pp. 12; 2 colored maps, topography and geology.

No. 189. Barnesboro–Patton Folio, Pennsylvania; by Marius R. Campbell, Frederick G. Clapp, Charles Butts. In cooperation with the State of Pennsylvania. Pp. 13; 3 maps, topography and geology, 11 figs.

No. 190. Niagara Folio, New York; by E. M. Kindle and Frank B. Taylor. Pp. 26; 4 maps, topography and geology, 3 pages of illustrations with 25 plates.

Professional Papers.—No. 76. The San Franciscan Volcanic Field, Arizona; by Henry H. Robinson. Pp. 213; 14 pls., 36 figs. See notice on p. 202, February number.

No. 85–B. The Mud Lumps at the Mouths of the Mississippi; by Eugene W. Shaw. Pp. 11–27; 3 pls. 6 figs.

No. 85–C. Interpretation of Anomalies of Gravity; by Grove K. Gilbert. Pp. 29–37; one plate, one figure.

Mineral Resources for the United States in 1912, numerous advance chapters.

Bulletins.—No. 531. Contributions to Economic Geology, 1911. Part II, Mineral Fuels. Marius R. Campbell, Geologist in charge. Pp. 361; 24 pls., 10 figs.

No. 536. The Noatak–Kobuk Region, Alaska; by Philip S. Smith. Pp. 160; 15 pls., one fig.

No. 538. A Geologic Reconnaissance of the Circle Quadrangle, Alaska; by L. M. Prindle. Pp. 82; 13 pls., 2 figs.

No. 539. Some Ore Deposits in Northwestern Custer County, Idaho; by Joseph B. Umpleby. Pp. 104; 10 pls., 4 figs.

No. 542. Mineral Resources of Alaska: Report on Progress of Investigations in 1912; by Alfred H. Brooks and others. Pp. 308, 10 pls., 7 figs.

No. 545. Bibliography of North American Geology for 1912, with subject index; by John M. Nickles. Pp. 192.

No. 555. Results of Spirit Leveling in Indiana 1897 to 1911, inclusive. R. B. Marshall, Chief Geographer. Pp. 51.

Water–Supply Papers.—No. 295. Gazetteer of Surface Waters of California, Part I. Sacramento River Basin. Prepared under the direction of John C. Hoyt, by B. D. Wood. Pp. 99. Washington, 1912.

Nos. 302, 303. Surface Water Supply of the United States 1911, prepared under the direction of M. O. Leighton. No. 302, Part II. South Atlantic Coast and Eastern Gulf of Mexico Drainage Basins; by M. R. Hall and C. H. Pierce. Pp. 90, 4 pls. No. 303, Part III. The Ohio River Basin; by A. H. Horton, M. R. Hall, and H. J. Jackson. Pp. 112; 4 pls.

No. 319. Geology and Ground Waters of Florida; by George C. Matson and Samuel Sanford. Pp. 445; 17 pls., 7 figs.

No. 320. Geology and Water Resources of Sulphur Spring Valley, Arizona; by O. E. Meinzer and F. C. Kelton, with a section on Agriculture by R. H. Forbes. Pp. 231; 15 pls. and 32 figs.

No. 333. Ground Water in Boxelder and Tooele Counties, Utah; by Everett Carpenter. Pp. 90, 2 pls., 9 figs.

No. 334. The Ohio Valley Flood of March–April, 1913 (including comparisons with some earlier floods); by A. H. Horton and H. J. Jackson. Pp. 96; 19 tables, 22 pls.

No. 337. The Effects of Ice on Stream Flow; by William G. Hoyt. Pp. 77; 7 pls.

3. *Commission Internationale des Glaciers. Les Variations Périodiques des Glaciers, XIII*me *Rapport, 1912;* by Charles Rabot and P. L. Mercanton. Annales de Glaciologie, viii, pp. 42-62, 1913. With Supplement, pp. 191-202.—Owing to the unusual climatic conditions, the glaciers of the Swiss Alps increased in volume during 1912 and more than compensated for the decrease recorded in 1911. Of 52 glaciers noted, 2 undoubtedly and 9 probably advanced during the year, while 25 show recession. The corresponding figures for 1911 based on 67 glaciers, are 1, 1, and 42 respectively. In the eastern Alps the conditions for glacial studies were very unfavorable during 1912, but such observations as were made indicate that while three small glaciers advanced slightly, the tendency to decrease is still maintained. The few glaciers measured in the Italian Alps are with one exception receding. While certain of the glaciers about Mont Blanc and the Massif du Pelvoux exhibit an increase of mass above their snouts, the tendency to a general increase suggested by the behavior of the glaciers in the French Alps during 1911 was not evident in 1912. L. Gaurier reports for the Pyrenees that the ice masses in the basin Gave de Pau have for several years shown indications of an increase in length and volume. The glaciers of north Sweden continue to grow in length. In Norway all glaciers in the Jotunheim mountains exhibited decreases during 1911–12, varying from 0·2 to 29 meters. On the western and northern borders of Norway four tongues of the Jostedalsbrae, two in the Okstind mountains and one of the Svartis glaciers, have advanced; 27 others have receded. Observations of North American glaciers indicate marked retreat of ice tongues on Mount Rainier during the period 1909–1912. Recent surveys show a decrease in length of the Nisqually glacier of 300 meters since 1885. The Alaskan glaciers are in retreat and the grand Pacific glacier shows the unprecedented decrease of 25 kilometers since 1879. During the months of June and July, 1912, this glacier retreated more than 1½ kilometers. Scattered observations in Greenland indicate that conditions tending to decrease of glaciers are prevalent.

The reports of the International Glacier Commission are becoming each year more valuable because of the increased attention paid to the variation in the controlling climatic factors.

H. E. G.

4. *Text-book of Paleontology.* Adapted from the German of Karl A. von Zittel. Second edition, revised and enlarged by Charles R. Eastman, with the collaboration of other paleon-

tologists. London, 1913 (Macmillan and Co. Price $6.50).—Invertebrate paleontologists have long been looking for the second edition of the well known Zittel-Eastman Text-book of Paleontology, the first edition of which was published in 1900 and has long been out of print. The first edition had 706 pages with 1476 illustrations; the new book has grown to 839 pages and 1594 illustrations. In the previous edition, the editor had the assistance of twelve collaborators, and of these three only have taken part in the present edition, but the latter contains the work of fourteen new collaborators. It is essentially an American revision, with the assistance of Doctor W. T. Calman of the British Museum (Natural History) and Doctor Anton Handlirsch of the Royal Natural History Museum, Vienna.

The book is as up-to-date as a work of this kind can be and treats of all classes of invertebrates found fossil. More than 5400 genera are considered, illustrated, or referred to the proper place in the organic classification and the geologic column.

The greatest changes from the first edition are in the following groups: Foraminifera (by Cushman), Hexacoralla (Vaughan), Graptolitoidea (Ruedemann), Cystoidea and Crinoidea (Springer), Echinoidea (Jackson), Bryozoa (Bassler, who has seen to it that the Trepostomata Bryozoa no longer parade among the tabulate corals), Brachiopoda (Schuchert), Gastropoda (Dall), Ammonoidea (J. P. Smith), Trilobita (Raymond), Branchiopoda and Ostracoda (Bassler), Malacostraca (Calman), Merostomata (John M. Clarke), scorpions, spiders, etc. (Petrunkevitch), and Insecta (Handlirsch).

The book will be of great service to all paleontologists and teachers of graduate courses in paleozoology and stratigraphic geology. C. S.

5. *The Life of the Mollusca;* by B. B. Woodward. Pp. xi, 158; 32 plates and map. London, 1913 (Methuen and Co.).—This book, by a well known naturalist, gives an accurate summary of the living Mollusca from a semi-popular viewpoint, with an abundance of good illustrations arranged in thirty-two plates at the end of the work. At six shillings the book is not expensive, though one wishes for better binding. The reader is first made acquainted with the general structure of the various types of shell-fish, and then with their classification. Chapter three recites very briefly the geological history of the phylum and the next chapter gives the zoogeography as arranged in nineteen marine "provinces" and thirty-one land "regions," that are also indicated on a mercator map of the world. How the molluscs live is next described, and following it their reproduction and something of their evolution. The final chapter is on instinct, intelligence, and utility. C. S.

6. *Victoria Memorial Museum, Bulletin No. 1, 1913.*—This new serial of the Geological Survey of Canada is intended to bring out the results of the staff at work upon the collections in the Victoria Memorial Museum at Ottawa. The articles in the

first issue deal with Paleontology (9 papers), Paleobotany (2), Mineralogy (1), Natural History (3), and Anthropology (1).

C. S.

7. *Atlas der Krystallformen ;* von Victor Goldschmidt. Volume II ; Text, pp. 200 ; Atlas, plates 251. Heidelberg, 1913 (Carl Winter's Universitätsbuchhandlung).—The first volume of Goldschmidt's Atlas, published six months since, was noticed in the number for October, 1913 (p. 313), and at that time the plan of the author was discussed at length. It is gratifying to receive now volume II of the text and plates, and to have thus an evidence of the promptness with which this great work is being carried through. Mineralogists are to be congratulated, as well as the author himself, that the completion of the work may be looked for at no distant date. The present volume includes all the species from calaverite to cyanochroite, and the extraordinary thoroughness of the work will be appreciated from the fact that the single species calcite extends over 152 plates, with a total of 2544 figures. The wealth of information thus given to the mineralogical student is really extraordinary ; the figures are grouped according to habit and the completeness of the whole leaves nothing to be desired. Other species also treated at length are cerussite, with 476 figures ; celestite, with 270; columbite, with 90 figures. The accompanying text gives exhaustive references to the literature, with tabular summaries of the forms noted on the different species.

8. *Paléontologie Végétale—Cryptogames cellulaires et cryptogames vasculaires ;* by Fernaud Pelourde ; preface by M. R. Zeiller. Small 12mo. Pp. xxviii, 360 with 80 figures in text. Paris, 1914 (Encyclopédie Scientifique ; Octave Doin et Fils).—One of a five-franc series covering the pure and applied sciences. This is the most compact paleobotanic text thus far published. Print and illustrations are good, and the references to original sources usually given. Including the recent results of Paleozoic fern study, this little book is timely and must prove usable. It may be pointed out, however, that while the initial topic Algæ occupying 14 pages might have been extended, the important examination of boghead and cannel coals by Jeffrey has been overlooked. He has shown conclusively that forms like *Pila bibractensis*, etc. (fig. 1) are not algal but the reproductive spores of the commoner types of coal plants.

G. R. W.

9. *Fabre, Poet of Science ;* by Dr. C. V. Legros ; with a preface by J. H. Fabre. Translated by Bernard Miall. Pp. 352. New York, 1913 (The Century Co.).—Fabre's ten volumes of *Souvenirs entomologiques* contain the most marvelous and vivid accounts of the habits and instincts of the insect world that have ever been written. The style of the original publication was so unattractive, however, and the author of so modest a nature that the work remained for many years almost unknown even by entomologists. But within the past two years Fabre's fame has spread throughout the world, and many of the wonderful

stories of his discoveries of the insects' domestic life have been translated from the French, published as attractive books, and have gained a wide popularity. Today he is everywhere recognized as both a naturalist and a poet.

The story of the life of this remarkable man reveals many years of adversity, of struggle against poverty, of rebuffs on all sides due to a complete lack of appreciation of his work, but it also shows a long life of entire devotion to his chosen field of study. It is a joy to feel that Fabre has lived to the age of more than ninety years, and has at the last received the homage that the world has given so tardily.

The book in hand is more than a mere biography, for the writer discusses the importance of Fabre's contributions to animal psychology and their relation to the generally accepted biological theories. A summary of Fabre's conclusions as to the meaning of color patterns, of structural peculiarities, of characteristic behavior, and of the marvelously complex instincts of the various groups of insects, shows the need of a re-examination of the factors thought to be concerned in the process of evolution.

W. R. C.

10. *Eleventh Annual Report of the Bureau of Science, Philippine Islands;* by Alvin J. Cox. Pp. 83, with 72 plates. Manila, 1913 (Bureau of Printing).—The report consists of a concise statement of the work accomplished during the year in the various sciences and industries with which the Bureau is concerned. The investigations in hand and completed are briefly described and are illustrated by excellent plates. The full reports of these investigations are printed in the special publications of the Bureau. W. R. C.

11. *Diseases of Tropical Plants;* by Melville T. Cook. Pp. xi, 317; with 85 figures. London, 1913 (Macmillan & Co.).—For very evident reasons, phytopathological research in the tropics is as yet undeveloped compared with the recent advances of vegetable pathology in the temperate zones. To quote from Dr. Cook, "The literature is very much scattered, frequently popular, without even a scientific reference to make the identity of the disease possible, sometimes technical, and with little data as to the economic importance of the disease under consideration, and often unreliable." Chiefly, for this reason, a work of this character is of value, since it contains the most important facts thus far known relating to the common diseases of tropical plants, and furnishes a ground work for future investigation along this line.

After introductory chapters on the structure and functions of plants, the classification of fungi, and the causes of plant diseases, such plants as the following are taken up, and the principal diseases from which they suffer are described: sugar cane, corn, rice, cotton, citrus fruits, pineapple, banana, fig, guava, olive, tobacco, coffee, tea, cacao, rubber and cocoanut. The destructive diseases are added of certain plants which are grown in the tropics as well as in the temperate zones, e. g. potato, tomato,

egg plant, bean, pea, peanut, sweet potato, cucumbers, melons, etc. Chapters on prevention and control methods, fungicides and spraying apparatus, and a bibliography conclude the book. For the tropical planter a manual of this sort will undoubtedly be of great value, and it will be also welcomed by the plant pathologist. A. H. G.

III. Miscellaneous Scientific Intelligence.

1. *Report of the Secretary of the Smithsonian Institution*, Charles D. Walcott, for the year ending June 30, 1913. Pp. 119. Washington, 1913.—Expansion in the direction of research and exploration is a feature of the recent growth of the Smithsonian under its present Secretary. The report, now issued, outlines numerous investigations going on and planned in these lines. Among these several may be mentioned. The plans have been formulated and the work already started for a geologic survey of Panama, in which the Canal Commission and the Geological Survey will also take part. The biological survey of the Canal Zone, commenced in 1910, was completed the past year as far as the field work is concerned, and some of the results have been published. Other work of this character includes the Rainey African Expedition, explorations in Borneo and in Siberia, the anthropological investigations in Peru by Dr. Hrdlička, and also the work of the Secretary himself in the Canadian Rockies. The second award of the Langley medal for progress in aërodromics was made to Mr. Glenn H. Curtiss, and it is interesting to note a statement recently made in public print that a reproduction of Langley's original flying machine, equipped with a modern motor, is to be used for practical demonstration in the near future.

The publications of the Institution for the year make a total of 6,260 printed pages, with an aggregate distribution of nearly 183,000 copies of pamphlets and bound volumes. In the work of International Exchange, the matter handled has increased from 318,000 lbs. in 1898 to nearly 600,000 in 1913. The progress made in the National Museum, the Zoological Park and in other directions of the Smithsonian's activities is also outlined and in a series of nine Appendixes detailed statements from the gentlemen in charge are given. With reference to the work of the Astrophysical Observatory, the director, Mr. C. G. Abbot, states that "The observations at Bassour, Algeria, taken in connection with those made simultaneously at Mount Wilson, Cal., have established the variability of the sun. A variability connected with the sun-spot cycle has also been shown. The mean value of the solar constant of radiation has been fixed, it is thought, within 1 per cent. From about 700 observations, extending over the time interval from 1902 to 1912 and taken at different altitudes from sea level to 4,420 meters, the mean value is 1,932 calories per square centimeter per minute. Pyrheliometers have been sent up

by means of sounding balloons to very great altitudes, and preliminary results indicate that they give values of the solar radiation similar to those found by high and low sun observations on homogeneous rays." Volume III of the Annals, including the work of the years 1907 to 1912, and published the past year, is noticed in vol. xxxvi, p. 650.

Among the publications of the Smithsonian Institution may be mentioned the following relating to the Bureau of Ethnology :

Twenty-eighth Annual Report, 1906–1907. Pp. 308, xxxv ; 103 plates, numerous text figures.

Bulletin 53. Chippewa Music, II ; by Frances Densmore. Pp. xxi, 341 ; 45 pls., 6 figs.

Bulletin 54. The Physiography of the Rio Grande Valley, New Mexico, in Relation to Pueblo Culture ; by Edgar L. Hewett, Junius Henderson, and Wilfred W. Robbins. Pp. 76 ; 11 pls , 2 figs.

2. *Library of Congress. Report of the Librarian of Congress*, Herbert Putnam, *and Report of the Superintendent of the Library Building and Grounds*, Bernard R. Green. For the Fiscal Year ending June 30, 1913. Pp. 269, with 6 illustrations. Washington, 1913.—The appropriations for the Library of Congress for 1914 are some $608,000, or considerably in excess of those for 1913. The number of accessions the past year includes nearly 116,000 volumes and pamphlets, a total which has only been twice exceeded in the past fifteen years. No large groups of printed books were presented, but an aggregate of 11,256 pieces were received by private gift from many individuals. The Library of Congress has been accepted to such an extent as a model by the larger libraries in the country that the annual report of the librarian is always interesting and instructive, particularly to those concerned with this line of work. It may be noted that the total number of volumes catalogued during the year was 107,500, and that the process of classification has gone on steadily so that now the re-classified portion of the Library contains some 1,277,000 volumes. The Library now contains, in round numbers, 2,128,255 books and pamphlets, 135,223 maps and charts, 630,799 volumes and pieces of music, 360,494 prints (art); the manuscripts are numerous but cannot be definitely enumerated.

3. *Catalogue of the Lepidoptera Phalænæ in the British Museum*, Volume XIII. *The Noctuidæ;* by Sir George F. Hampson. Pp. xiv, 609; 127 figures in the text. London, 1913. —This volume is devoted to the remainder of the Noctuid subfamily *Catocalinæ* and the subfamilies *Mominæ* and *Phytometrinæ*. The first named includes here 44 genera and 379 species (or 107 genera and 1022 species in all for this subfamily); the *Mominæ* embrace 11 genera and 74 species, the *Phytometrinæ* 15 genera and 226 species.

Plates CCXXII–CCXXXIX, separately bound, accompany this volume.

4. *Napier Tercentenary Celebration.*—It is proposed to celebrate the tercentenary of the publication in 1614 of John Napier's great works on Logarithms by a Congress, to be held in Edinburgh on Friday, July 24, 1914, and following days. The celebration is to be under the auspices of the Royal Society of Edinburgh, and the President and Council now extend a general invitation to mathematicians and others interested in this coming event. The program announced shows that the celebration will contain many features of great interest. It is planned to issue a Memorial Volume containing the addresses delivered, etc., and a subscription of £2 by individuals, libraries, etc., will entitle them to this. Subscriptions and donations should be sent to the Honorary Treasurer, Mr. Adam Tait, Royal Bank of Scotland, Edinburgh. All interested in the proposed celebration are invited to communicate with the General Secretary of the Royal Society of Edinburgh, 22 George Street, Edinburgh, and to announce their intention of being present.

5. *International Electrical Congress.*—The International Electrical Congress is to be held at San Francisco, September 13 to 18, 1915, under the auspices of the American Institute of Electrical Engineers. Dr. C. P. Steinmetz has accepted the Honorary Presidency of the Congress. The deliberations of the Congress will be divided among twelve sections, which will deal exclusively with electricity and electrical practice.

Obituary.

Dr. Harry Rosenbusch, emeritus professor of geology and mineralogy at the University of Heidelberg, Baden, died at his home, after a brief illness, on January 20th. He was, with Zirkel, one of the early founders of the science of modern petrology, and his monumental work "Die Mikroskopische Physiographie der Mineralien und Gesteine," the fourth edition of which appeared (1905–1907) in four volumes, is recognized wherever geological sciences are pursued as the authoritative treatise and reference book in the field of microscopical petrography.

The reputation he had attained in his subject, together with his genial personality, and success as an instructor, drew, during the active working period of his life, many students to his laboratory from all parts of the world. Among them were many Americans who will be grieved to learn of the decease of their former master. He was able to communicate his own enthusiasm for petrological investigation to his pupils and through his published works and his teaching he probably exercised a greater influence over the development of the science than any petrologist of his time. L. V. P.

Sir David Gill, formerly H. M. Astronomer at the Cape of Good Hope, died on January 24, in his seventy-first year.

Dr. Théodose Tchernycheff, the eminent Russian geologist, director of the Comité Géologique de Russie and a member of many scientific societies, died on January 15 at the age of fifty-seven years.

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CONTENTS.

Page

ART. XV.—Fossil Dolphin from California; by R. S. LULL. (With Plate VIII) 209

XVI.—Note on the Occurrence of the Oriskany Formation on Parlin Stream, Maine; by L. V. PIRSSON and C. SCHUCHERT 221

XVII.—Upper Devonian Delta of the Appalachian Geosyncline; by J. BARRELL 225

XVIII.—Paleogeographical Affinities of the Alexandrian Series; by C. KEYES 254

XIX.—Use of Telluric Acid in the Determination of Bromine associated with Chlorine in Haloid Salts; by F. A. GOOCH and H. ISABELLE COLE 257

XX.—Wilkeite, a New Mineral of the Apatite Group, and Okenite, its Alteration Product, from Southern California; by A. S. EAKLE and A. F. ROGERS 262

XXI.—Rocks of the Cerro de Santa Ana on Paraguana, Venezuela; by T. A. BENDRAT 268

SCIENTIFIC INTELLIGENCE.

Chemistry and Physics—Rusting of Iron in Water, W. A. BRADBURY: Estimation of Periodates in the Presence of Iodates and Iodides, MÜLLER and WEGELIN, 273.—Dictionary of Applied Chemistry, E. THORPE: Allen's Commercial Organic Analysis, W. A. DAVIS and S. S. SADTLER: Chemistry, Inorganic and Organic, C. L. BLOXAM, 274.—Quantitative Chemical Analysis, CLOWES and COLEMAN: Industrial Organic Analysis, P. S. ARUP: Radioactive Origin of the Color of Zircons, R. J. STRUTT, 275.—Suppression of the Photoelectric Effect, K. FREDENHAGEN and H. KÜSTNER, 276.—Effect of Temperature on X-ray Diffraction Patterns, DEBROGLIE, etc.: Measuring the Pressure Produced in the Detonation of High Explosives or by the Impact of Bullets, B. HOPKINSON, 277.

Geology and Natural History—Thirty-fourth Annual Report of the Director of the United States Geological Survey: Publications of the United States Geological Survey, 280.—Commission Internationale des Glaciers: Textbook of Paleontology, C. R. EASTMAN, 282.—Life of the Mollusca, B. B. WOODWARD: Victoria Memorial Museum, Bulletin No. 1, 1913, 283.—Atlas der Krystallformen, V. GOLDSCHMIDT: Paléontologie Végétale, F. PELOURDE: Fabre, Poet of Science, C. V. LEGROS, 284.—Eleventh Annual Report of the Bureau of Science, Philippine Islands: Diseases of Tropical Plants, M. T. COOK, 285.

Miscellaneous Scientific Intelligence—Report of the Secretary of the Smithsonian Institution, 286.—Report of the Librarian of Congress, etc.: Catalogue of the Lepidoptera Phalænæ in the British Museum, Volume XIII, 287.—Napier Tercentenary Celebration: International Electrical Congress, 288.

Obituary—H. ROSENBUSCH: D. GILL: T. TCHERNYCHEFF, 288.

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FOURTH SERIES

VOL. XXXVII—[WHOLE NUMBER, CLXXXVII].

No. 220—APRIL, 1914.

Smithsonian Institution
APR 2 1914
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NEW HAVEN, CONNECTICUT.

1914.

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AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

Art. XXII.—*The Rodadero (Cuzco, Peru),—A Fault Plane of Unusual Aspect;* by Herbert E. Gregory.*

Introduction.

Overlooking the city of Cuzco, perched high on a jutting eminence, stands the famous Inca fortress of Sacsahuaman. The enormous size of the blocks used in its construction, the incredible labor expended in quarrying and transporting, and the skill exhibited in nicely fitting the stones into walls without mortar, give this structure a unique place among the works of prehistoric man. Seven hundred feet north of Sacsahuaman and at a somewhat higher elevation is the equally famous Rodadero, a grooved and polished rock mound in which have been cut the "Seats of the Incas" (fig. 1).

Topographically the Rodadero is one of four knobs or bosses of intrusive igneous rock rimmed about with massive blue limestone which forms the plateau overlooking Cuzco from the north. Three of these intrusive masses are more or less cloaked with vegetation and the products of weathering; the Rodadero, however, is bare, singularly fresh and firm, and gives the impression of a ledge of rock stripped and polished by the hand of man. The insignificant influence of weathering revealed by the exposed surface of the Rodadero is worthy of comment, in view of the fact that at nearby localities disintegration of rock of identical character has reached an advanced stage. Thus in the banks of the Tullumayo the firmer portions of the basic igneous ledges are separated into blocks with rounded edges, and other portions consist of concentrically weathered bowlders embedded in a disintegrated groundmass (fig. 2), and still other parts of the original mass are represented by a yellow-white, clay-like

* Geologist, Peruvian Expedition of 1912.

substance containing weathered crystals of feldspar and augite. Along the Huatanay large masses of the rock have been converted into epidote. It would appear, therefore, that the Roda-

Fig. 1.

Fig. 1. "The Seats of the Incas." South slope of the Rodadero; highly polished seats accurately cut from massive diorite. According to tradition these seats were used by the royal family during the construction of Sacsahuaman.

dero has been recently exposed through natural agencies aided perhaps by artifical stripping during the process of filling and terracing which has greatly modified the original topography.

Rock forming the Rodadero.

As seen in the ledge the rock forming the Rodadero is dark grey in color, with a greenish tinge when viewed in certain lights. The weathered portions are light gray or even yel-

Fig. 2.

Fig. 2. Weathered diorite forming east bank of Tullumayo; compare with figures 4 and 5.

lowish and spotted with green. Aggregates of yellow-green epidote varying in size from a pea to clusters eight to ten inches in diameter are irregularly distributed through the mass and are particularly prominent along joints. The rock as a whole appears to be massive, fine-grained, and of granitic

texture; but even in the freshest hand specimens black crystals of augite and minute clusters of epidote may be differentiated from the denser groundmass, thus giving the rock a porphyritic appearance. Petrographic analysis of the Rodadero rock, described by Squier* as "amphibolic rock" and again as "trachytic rock," by Markham† as "limestone," and by Dueñas‡ as "altered diabase," revealed the following constituents: Well-preserved crystals of augite, fresh or kaolinized plagio-

Fig. 3.

Fig. 3. Incaic wall in Calle del Triunfo, Cuzco, built of rock identical with that forming the Rodadero (A. H. Bumstead, photo.).

clase feldspars near andesine in composition, chlorite probably representing biotite and hornblende, apatite and iron grains in very small amounts; epidote occurs abundantly distributed as grains and clusters. The rock forming the Rodadero may therefore be classed as an augite diorite porphyry.

Rock of this type taken from the quarries adjoining the city was highly prized by the architects of the Inca dynasty, in spite of the labor and skill involved in working the resistant material. The best preserved walls of ancient Cuzco, for example those bounding Calle del Triunfo (fig. 3), in which the stones are fitted and polished with wonderful skill, are built of this material.

* Peru: Incidents of travel and exploration in the land of the Incas, 1877, pp. 468 and 476.

† Cuzco: A Journey to the Ancient Capital of Peru, 1856, p. 115.

‡ Cuerpo de Ing. de Min. del Peru, Bol., liii, p. 179.

The ledges forming the Rodadero are traversed by incipient joints and broken by numerous faults of small displacement along which slickensides have been developed—features common to both igneous and sedimentary rock masses within the province of Cuzco.

The fluted surface.

The unusual feature of the Rodadero and the one which gives it its name (Spanish, *rodada*, a rut), is the remarkable series of polished grooves which ornament the entire surface of the irregular knob (figs. 4 and 5). An area exceeding an acre is occupied by grooves whose width varies from a few inches to four or five feet, and whose depth varies between a fraction of an inch and four feet. Smaller flutings and delicate striæ traverse the troughs and crests of the larger depressions in a longitudinal direction. Microscopic abrasion lines have smoothed and polished the channels and ridges to such a degree that one may slide down the inclines without damage to clothing—an amusement indulged in by natives and tourists alike; and, if tradition is to be accepted, by the Inca rulers themselves. The larger and smaller grooves are continuous and parallel for 100 to 300 feet, and at one locality thirty-two parallel channels with a combined width of fifty feet were traced for a distance of 180 feet. About 90 per cent of the grooves and ridges extend S. 30° W., but other trends are represented as indicated below.

The large area exposed, the freshness and perfection of carving, the continuity and parallelism of the striæ which give this exposure a unique character, have naturally attracted the attention of students of nature. Squier* described the Rodadero ("La Piedra Lisa") as a rock "squeezed up in plastic state between irregular and unyielding walls, and then hardened into shape with a smooth and glassy surface." The statement of Rivero and Von Tschudi† illustrates the extreme philologic method of scientific research, and the liability of being led astray by a name: "A short distance from the fortress is a large piece of amphibolic rock known by the name of 'the smooth rolling stone' which served and still serves for diversion to the inhabitants by rolling like a garden roller having a sort of hollow formed in the middle through friction."

Dueñas, whose "Aspecto Minero del Department del Cuzco"‡ is worthy of high commendation," describes the Rodadero as a glaciated surface, a view also held by Posnansky.§ Sivi-

* Peru, 1877, p. 476.

† Peruvian Antiquities, 1853, p. 249. M. E. Rivero and J. J. von Tschudi. Translated into English by F. L. Hawks.

‡ Cuerpo de Ing. de Min. del Peru, Bol., liii. pp. 25-26, 1907.

§ Bol. Oficina Nac. Estadist, No. 64-66, La Paz, 1911.

Fig. 4.

Fig. 4. East slope of Rodadero, looking south. Note three sets of minor faults.

Fig. 5.

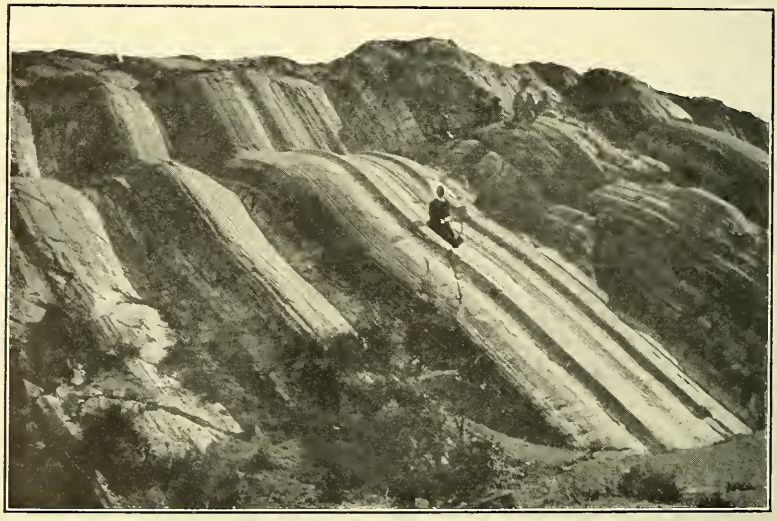


Fig. 5. The "Toboggan Slide," Rodadero. Note the variation in the depth of the grooves.

richi* considers the Rodadero an igneous intrusion molded by glaciers before the molten rock had cooled. The popular explanation of the smoothed, hummocky surface of the Rodadero is in line with the views expressed above, and it must be admitted that we are dealing with a remarkably exact imitation of a "rôches moutonnés" surface. The resemblance between the Rodadero and glacially eroded surfaces, made familiar by field experience, is in fact so close that my first impression was in accord with the views of Dueñas and Posnansky in spite of the warning of my observant colleague, Professor Bowman.† The theory that an ice sheet played a part in molding the Rodadero

Fig. 6.

Fig. 6. Ledge of limestone adjoining the striated Rodadero. Compare with figures 4, 5, 7, and 8.

was, however, abandoned in view of the following observations:

(1) There is no evidence of glacial erosion in the Cuzco region at so low an elevation. The Rodadero stands at 11,700 feet, while the lowest moraines on the Sencca, three miles distant, are intersected by the 12,500-foot contour. (2) The striations on the Rodadero are duplicated on another igneous knob one-half mile to the eastward, but the projecting ledges of resistant limestone immediately surrounding the igneous masses show no signs of glacial action either on the surface or in recent excavations. (Fig. 6.) The freshness and perfection of

*Tesis Universidad del Cuzco, p. 18; Topografia Infantil Cuzco, 1911.
†This Journal, xxxiii, p. 317, 1912.

detail suggest late Pleistocene glaciation, and it is difficult to conceive that limestone and sandstone ledges could have failed to record the effects of long-continued action of an ice mass of the proportions required for the work at the Rodadero. (3) No graving tools in the shape of polished or striated bowlders and

Fig. 7.

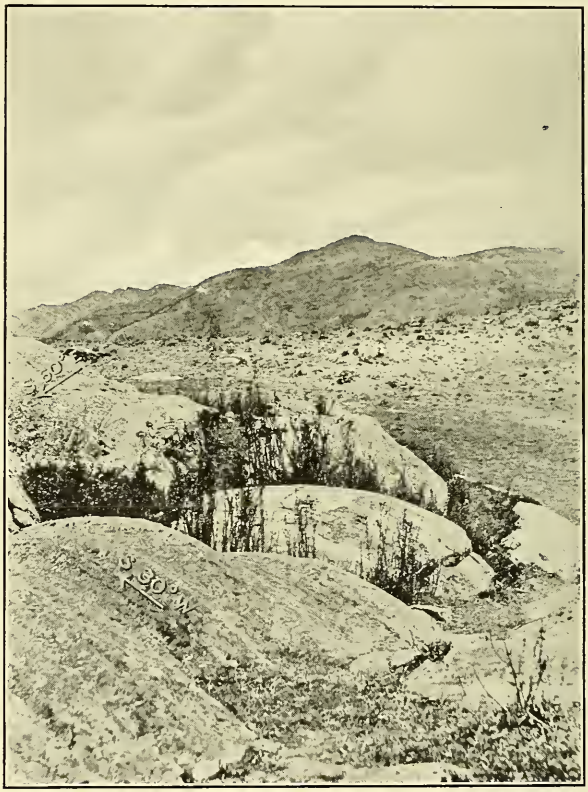


Fig. 7. A portion of the Rodadero, showing striæ trending in two directions. View looking west.

no erratics were found on the surface nor in the gravels adjoining. (4) While the general trend of the grooves is S. 30° W., other directions were noted, and at one locality deep grooves running S. 30° W. are succeeded, after a break of a few feet, by equally well-marked striations running S. 60° E. (fig. 7). (5) The lee side and stoss sides of the entire mass and of individual

knobs are alike affected. There is no plucking. (6) In places a paste of broken igneous fragments overlies the smoothed and fluted surface. The removal of the brecciated material reveals the familiar grooves beneath. (7) Two slabs pried from the

FIG. 8.

FIG. 8. Normal fault, post-dating the major thrust fault which produced the slickensides.

ledges were found to be striated on both their lower and upper surfaces. (8) Microscopic examination of the rock shows that the surface zone has been modified in texture—the sort of metamorphism resulting from pressure of rock on rock, not of ice on rock.

The Rodadero a fault plane.

Field relations and rock texture indicate that the diorite mass whose striated surface forms the Rodadero is intrusive into sediments of Mesozoic age. However, the smoothed, unweathered exposures immediately adjoining the limestone outcrops exhibit no modification of texture incident to cooling and no interfingering of igneous and sedimentary rock. In fact the theory advanced by certain observers that the Rodadero represents an ancient cooling surface is quite out of harmony with the field evidence as well as with the theories of the mechanics of igneous intrusion. The presence of limestone in immediate contact with diorite—a relation which furnishes opportunity for solution along the contact—has doubtless facilitated the stripping of the igneous boss.

The Rodadero is believed to be a portion of a thrust fault plane marked by an unusual expression of slickensides. Unlike normal slickensides the striated grooves of the Rodadero occur indiscriminately on flat, convex, concave and undulating surfaces; and although generally straight and parallel they may also be seen curving gently around minor knobs. The criteria usually employed to distinguish slickensides from striæ of glacial origin are not applicable.* The groups of striæ of various orientation merge imperceptibly into one another and are apparently contemporaneous, thus indicating the presence of stresses opposed to the dominant direction of movement. Readjustment of pressures following the major faulting has resulted in the production of minor, normal faults which interrupt the continuity of the grooves. These faults, trending roughly 90° and 45° to the prevailing direction of striæ, are themselves marked by slickensides and fault breccia and exhibit prominent "drags" (fig. 8).

* Geikie: Structural and Field Geology, p. 309.

ART. XXIII.—*The Occurrence and Genesis of a Persistent Parting in a Coal Bed of the Lance Formation;** by G. SHERBURNE ROGERS.

DURING the examination of the Tullock Creek coal field, Montana, in 1912-13, the writer discovered a coal bed containing everywhere a curious parting which, because of its uncommon physical characters, seems to merit a brief notice. The material resembles a slightly carbonaceous sandstone and was so considered in the field; but, owing to its persistence throughout the area examined, it was later studied microscopically and was found to be an almost pure aggregate of delicate crystals undoubtedly formed in situ. The occurrence of such a deposit in the midst of a mass of heterogeneous and largely continental sediments is surprising. The writer has seen similar partings in other coal beds in this region, and several other geologists of the U. S. Geological Survey have mentioned like instances both in the Cretaceous and Tertiary coal fields of the west and in the Carboniferous fields of the east; it is believed, therefore, that this phenomenon may be not uncommon and may have some general bearing on the accumulation and alteration of sedimentary rocks. The writer is indebted to Dr. F. W. Clarke and Mr. E. S. Larsen, of the U. S. Geological Survey, for advice and helpful criticism.

Occurrence.—The Tullock Creek coal field is located on the east side of Bighorn River, Montana, in the angle formed by its junction with the Yellowstone. The coal bed here described outcrops also in the Pine Ridge field on the west side of the Bighorn, and a brief examination of that area was also made by the writer. The data here presented were gathered in both fields, which together form an area 36 miles in an east-west direction and 24 miles in a north-south.

The coal bed in which the parting occurs belongs to the Lance formation, which is Cretaceous or Tertiary in age. The Lance in this district comprises about 1,200 feet of sandstone and shale, the lower 900 feet of which contains no coal and is probably in part of brackish water origin. The upper 300 feet is coal-bearing, is somewhat different in color from the lower portion, and is probably of continental origin. The strata in most of the area lie almost flat and have suffered practically no metamorphism. The Lance formation is of widespread extent, occurring as far east as central North and South Dakota, and as far south as central Wyoming; and it is everywhere characterized by the lenticular and irregular habit of the strata, and especially the coal beds.

*Published by permission of the Director, U. S. Geological Survey.

In this district the coal bed containing the parting marks the base of the coal-bearing member of the Lance. The bed is not regular in thickness and possibly not even continuous throughout the area examined, but is made up of a number of lenses* which range in extent up to 40 square miles or more. It is probable that the vegetal matter was laid down in a series of semi-independent swamps during approximately the same period of time, a condition which has given rise to a series of lenses which are at exactly or very nearly the same horizon. It is not known whether these lenses are isolated or whether they are connected by a thin layer of carbonaceous material and therefore constitute one bed; but it is certain that they are all at the same stratigraphic horizon, and in this discussion will therefore be treated as a unit.

The strata above and below the bed also vary greatly in character and thickness. The immediate roof and floor are commonly carbonaceous shale, although bluish or greenish shale or sandstone have been observed. About 10 feet above the bed is a sandstone which is as much as 30 feet thick in some localities and entirely absent in others. In some localities there is a prominent sandstone underlain by greenish shale from 10 to 40 feet below the bed; in other places the bed is directly underlain by the greenish shale and the sandstone is absent. As stated above, the irregularity of the formation is one of its most striking characteristics.

Notwithstanding the lenticularity of the coal bed, it contains a parting of almost constant thickness at every point at which it was examined. The detailed examination was restricted chiefly to the areas in which the bed is over 18 inches in thickness, but in some other localities the horizon was used as a datum plane and much information concerning it was thus collected. The parting almost invariably occurs in the upper third of the bed and varies only slightly in thickness. It averages $\frac{3}{4}$ of an inch and is commonly between $\frac{1}{2}$ and $1\frac{1}{4}$ inches in thickness. It is generally bordered by good clean coal, although in places it is associated with impure coal or bone. It persists even where the bed is very thin and generally maintains its characteristic thickness and position in the bed. In one locality the bed is represented by only 2 inches of bone but the parting is present and is about half an inch thick. Its persistence and regularity are thus in striking contrast to the character of the rest of the bed and to the formation, a fact which induced the writer to examine it more particularly in the office.

Lithology and composition.—The material of which this parting is composed is granular and closely resembles a brown

*In this examination, coal beds less than 18 inches in thickness were not mapped; the lenses referred to are therefore considered as delimited by the line along which the coal is 18 inches thick.

carbonaceous sandstone. In the mass there is little lamination, which distinguishes it at once from ordinary carbonaceous shale. It is generally mixed with a certain amount of carbonaceous material, and contains plant impressions. Not uncommonly the roots and plant stems are in place and are perpendicular to the parting, having apparently grown directly

Fig. 1.

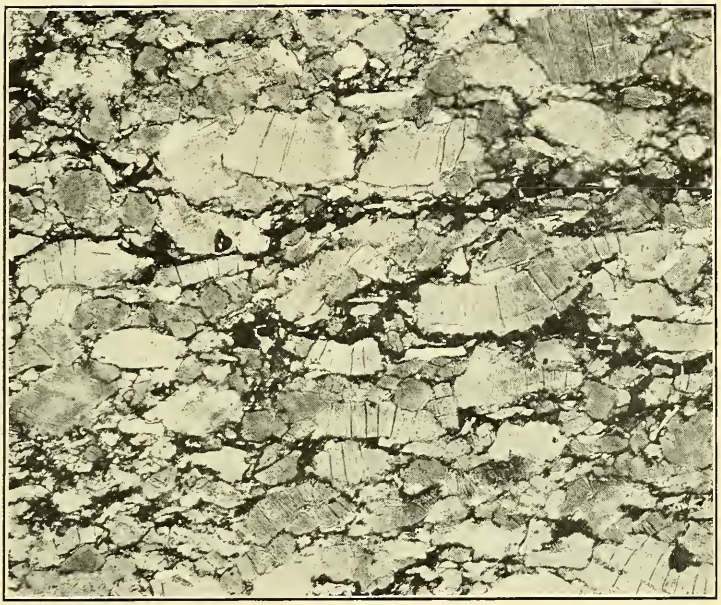


Fig. 1.—Photomicrograph of parting (magnification 48 diameters). The black grains are coal; the white are quartz; the remainder are variously oriented crystals of the mineral in question.

through it. When fresh and unweathered the material is coherent and fairly tough, but on the weathered outcrop it is very friable.

The resemblance of this material to sandstone, however, is only superficial. The hand lens reveals numerous pearly cleavage faces, and an almost complete absence of grit is indicated when the material is ground between the teeth. The grains are soft and may be scratched with the finger nail, the hardness being 1·5.

Several thin sections of this material, collected from widely separated points, were prepared and examined with the micro-

scope, and several other specimens were examined as crushed fragments. All of the slides show the parting to be remarkably uniform in composition. It is made up to the extent of about 90 per cent of a curious vermicular-like mineral occurring in apparently well-formed crystals, the remainder being chiefly carbonaceous matter and quartz in small angular fragments. The mineral occurs generally in stout, curved crystals with perfect basal cleavage, as is shown in figure 1. It is rather strongly pleochroic, colorless to brown. The extinction is wavy and is parallel to the cleavage. N_g is 1·56 and N_p is a little over 1·55; the double refraction is ·012 or a little less. The mineral is negative in optical character and is biaxial, but the angle, though generally small, varies.

These characters all correspond closely with those of the mineral leverrierite,* which was first described by P. Termier in 1890. Termier states that the mineral is commonly associated or even intergrown with black mica, and that it is embedded in a clay groundmass. In some places it occurs associated with eruptive rocks, in others with black carbonaceous shale. He believes it to be of metamorphic origin and ascribes it to the action on the shale of heated waters bearing silica, lime, and magnesia.

A sample of the parting was analyzed by R. C. Wells, of the U. S. Geological Survey. The analysis is given below, and with it, for purposes of comparison, are shown the analyses of two samples of leverrierite.

	1	2	3
SiO_2	46·47	46·40	49·90
Al_2O_3 }	37·03	38·40	37·02
Fe_2O_3 }			3·65
MgO	·44		·30
CaO	·13	1·20	tr.
K_2O	undet.		1·13
P_2O_5		·50	
Ignition	15·67	15·00	8·65
	99·74	101·50	100·65

1. Parting. Analyst, R. C. Wells. 1913.
2. Leverrierite. Specimen probably impure.†
3. Leverrierite. Pure material from Rochebelle, France.‡

It will be noted that the analysis of the parting agrees very closely with that of the first sample of leverrierite but that it differs perceptibly from the second which is said to represent material of greater purity.

* Termier, P., Ann. d. Min., xvii, p. 372, 1890.
† Op. cit.
‡ Bull. Soc. Min., xxi, p. 27, 1899.

Leverrierite, as described by Termier, has the composition of muscovite with hydrogen partly or wholly replacing potassium and a little iron equivalent to aluminium; or, as stated to the writer by F. W. Clarke, it is the vermiculite or end member of the mica series. Its formula then is $HAlSiO_4$. However, the above analysis of the parting as recast gives $H_4Al_2Si_2O_9$, which is the composition of kaolin, a fact which seems strange in view of the striking resemblance in physical properties which this material bears to leverrierite. It is possible that the loss on ignition included a large amount of carbon occurring in the sample as mechanically mixed coal, which if allowed for would reduce the water and cause the analysis to approximate the formula $HAlSiO_4$; but unless this be assumed the mineral must be considered a variety of kaolin which for some reason has assumed most of the physical properties of leverrierite. Furthermore, inasmuch as leverrierite has only one molecule of H_2O as against two in kaolin, a difference which is presumably due to the conditions of moderate metamorphism which produce it, it would hardly be expected to occur in the practically unmetamorphosed strata of the Lance.

Genesis.—It has been shown that the parting is persistent and is of nearly constant thickness throughout an area of over 800 square miles; and that it is chiefly an aggregate of crystals which resemble leverrierite in physical properties but have the composition of kaolin. It must have formed in situ, and that it did not greatly disturb plant growth is shown by the presence in it of numerous vertical plant stems. Three theories of the origin of this material at once suggest themselves. It may represent an altered tuff; it may be an alteration product of a pure clay; or it may be a chemical precipitate.

The widespread occurrence of this parting at the same horizon suggests its derivation from wind-blown volcanic ash. Ash is not uncommon in these rocks, and if this material is of clastic origin it is difficult to imagine another manner in which this thin deposit, of constant thickness over a large area, could have formed. This was the field theory advanced to account for it; but microscopic examination at once revealed the fact that, if so, a thorough alteration and recrystallization must have taken place. It is possible that pure orthoclase might alter to sericite and then to kaolin under the influence of swamp waters; but there is no known tuff approximating so closely the composition of orthoclase as to yield this product directly. If this hypothesis be accepted, the removal of considerable excess silica, as well as thorough leaching of the potassium silicate formed in the alteration to sericite, must be postulated.

The next hypothesis, the derivation of this material from a clay deposit, meets at once with strong physical objections. In the Appalachian and interior coal fields, numerous examples

of the persistency of partings of constant thickness are known, but the coal in those fields is generally believed to have formed in swamps which were only a few feet above sea level, so that a very slight oscillation might submerge large areas. The swamp in which this parting was laid down was probably some distance above sea level, however, and it is difficult to imagine how a slight change in level, or a flood, in such a swamp could produce a deposit of constant thickness throughout the whole district. Although the parting varies slightly in thickness, it seems to vary irregularly; it does not appear to be thicker in any one general locality than in another, as would be expected if deposited by a freshet. If this objection be disregarded there are no chemical difficulties involved other than that which any hypothesis must meet, namely, the peculiar recrystallization of the material.

The last hypothesis is satisfactory from a physical standpoint, but involves obscure chemical reactions whose validity may well be questioned. Silica and aluminium hydroxide, the principal constituents of the parting, are both known to exist in solution in the colloidal state. Whether the two can exist together in the colloidal state without being precipitated is an open question; assuming that they can, it is conceivable that an influx of water carrying colloidal silica and alumina entered the swamp, and that the colloids were slowly precipitated by the organic acids in the swamp water. If they cannot, it is necessary to suppose that waters carrying alumina encountered those bearing silica in the swamp, and that the product was thereupon precipitated, a supposition that is rather improbable. This hypothesis best explains the complete crystallization of the mineral, in assuming that it is a primary crystallization of gelatinous material rather than a recrystallization of tuff or clay.

None of the above hypotheses is thus wholly satisfactory. There are grave chemical objections to the first, and the physical difficulties in the deposition of a thin layer of constant thickness over a large area militate strongly against the second. In the present state of our knowledge, the third hypothesis appears the most tenable, although the evidence is not at all conclusive. Despite the uncertainty which attaches to the origin of this parting, its occurrence is of scientific interest; and if it is, as the writer is inclined to believe, a not uncommon development, its importance in connection with the deposition and chemical alteration of certain sediments is manifest. It is hoped that in the future a wider application of petrologic and chemical methods will be accorded to sedimentary rocks and that the significance of this and other obscure deposits will be more fully understood.

Art. XXIV.—*About Climatical Variations;* by Henryk Arctowski.

Some striking correlations have been found between the temporary climatic anomalies of far distant regions of the globe. To recall attention to the discoveries made, it will be sufficient to mention the names of Blanford, Woeikow, Hildebrandsson, Pettersson, Meinardus, Kremser, Lockyer, Bigelow, Merecki, Mossman, and others. Now let us suppose an anomaly at two correlated centers of action of our atmosphere, *e. g.* at the Icelandic low pressure center and the high pressure area of the Azores. Evidently, if the barometric gradient between these two centers of action is increased during a certain lapse of time, the atmospheric circulation—and, therefore, the distribution and quantity of rainfall—will vary in Western Europe as well as in the Northeastern States and Canada. But what are these variations for a given variation at the centers of action?

As simple as this question seems to be, no serious attempt toward its solution has ever been made. And the same may be said about the other centers of action of atmospheric circulation. It is true that some researches of Teisserenc de Bort, Hann, Poincaré, Garrigou-Lagrange, and Exner may be mentioned, but the systematic work on the inter-action of the variations at the centers of action remains to be made.

Let us consider for a moment another question: does the temperature of our atmosphere remain constant from year to year, or from a period of a given number of years to the following period?

We have to admit, of course, that all the climates, all over the world, have been very much warmer during certain geological periods. We know also perfectly well that during the Pleistocene ice age the temperature at the earth's surface was very much lower than at present, and that similar important climatic variations have produced ice ages during different geological periods. But how about the climates of historic times, or the climates of, let us say, the last century or the last decade of years?

Certain periodicities of climatic variations have been advocated, discussed, contradicted, and may finally be admitted or rejected according to personal opinion. This is particularly the case of the 19-year period of Russell and the 35-year period of Brückner.

A simpler periodicity is the sunspot cycle correlation. Long ago, Köppen demonstrated the complexity of the phenomenon, since he found that the variation is direct under certain lati-

tudes and inverse under other latitudes. Newcomb discussed the problem anew and practically rejected the hypothesis that the solar cycle is an important factor, while nearly at the same time, Nordman demonstrated in a very elegant manner the influence of the sunspot variation upon the temperatures of the equatorial regions.

To show more plainly the difficulties of the problem, I have to refer to my own researches published in 1909.

Considering, for given localities, the series of annual means of temperature, we notice everywhere more or less important fluctuations. The curves expressing graphically the succession of figures show perfectly well-pronounced variations at certain localities differing completely from other variations of other localities. Some curves go down when other curves go up, and the length of time separating the maxima varies from one curve to the other. This shows that it is not possible to discuss the problem of climatic variations with the data of only a number of selected stations. All available data have to be taken into consideration and the problem has to be studied geographically.

The problem of the variations of terrestrial temperature is indeed absolutely similar to the problem of the mean elevation of the surface of the earth crust. The precision gained in the appreciation of the mean elevation of a continent depends on the precision of the utilized hypsometrical maps. The precision of an estimate of the mean depth of an ocean depends on the accuracy of the bathymetrical map; that is to say, on the number of recorded soundings.

Now, since in the case of temperature we also have to deal with depressions below the average and elevations above, the knowledge of the extent of these areas, covered by positive or negative departures, is evidently more necessary for the discussion than the figures for some isolated stations, where the temperature conditions may or may not correspond to the average conditions of the surrounding countries.

The work I have done was the mapping of all the temperature data I could obtain for the years 1891–1900. Then, considering the means of the decade 1891–1900 as being quasi-normal values, I have formed for each year and each station the departures from these means. These annual departures having been inscribed on maps, equidepartures lines have been drawn. The areas of positive departures (above the mean) have been called thermopleions, the areas of negative departures thermomeions or antipleions.

The result of the discussion shows that 1900 was a year of predominant thermopleions; the year 1893, on the contrary, a year of most predominant antipleions. Taking the probable areas into consideration, as well as the probable excess and

deficiency of temperature, I found that the difference in temperature between these two years must have been at least 0°·5 C.

Coming back to the question of sunspots, I will simply remark that 1893 was a year of maximum and 1900 a year preceding closely a most accentuated minimum. But this question is of less interest than the simple verification of the fact that the temperature of the terrestrial atmosphere is not constant. The simplest explanation of this fact is that the amount of heat radiated by the sun and received by the earth varies slightly. I will insist upon this question later.

1. *The pleionian variations.*

To simplify the reasoning I will define more plainly the pleionian variations.

To avoid the more or less regular annual variation, we have to take yearly means. But it is indifferent how we count the year, as long as we compare between them means of twelve consecutive months. By making consecutive yearly means for the one-year periods beginning with January, with February, March, and so on, and by comparing the curves expressing the succession of the figures, we can see how a negative departure of a given year passes progressively to a positive departure of another year.

I made such consecutive temperature curves for the entire series of observations recorded in Batavia, New York, and some other places. For the years 1900 to 1909 I compared a great number of such curves. Two facts of some importance are clearly demonstrated.

1°. That, although there are some most interesting agreements with the curve expressing the sunspot cycle, this cycle cannot be considered as being the main factor producing the pleionian variations, simply because the pleionian crests and depressions of the temperature curves repeat themselves 3 to 4 times more often than the maxima and minima of the solar curve.

And, 2°. The temperature curves of far distant stations, belonging to absolutely different climates, present in certain cases such striking coincidences, that it is impossible to ascribe them to simple chance circumstances.

I may add that the consecutive curves of rainfall, of sunshine records and of atmospheric pressure, also display pleionian variations and demonstrate the fact that we have to deal with more or less periodical alterations of the atmospheric circulation.

In order to make comparisons, a standard curve was necessary. The records of the exceptionally undisturbed climate of Arequipa, in Peru, gave this necessary standard.

The consecutive temperature curve of Arequipa, for the years 1900–1910, shows 4 characteristic crests and 4 depressions (fig. 1). The curve of Bulawayo, in Rhodesia, is absolutely similar to the Arequipa curve. The same may be said about the curve obtained from the Mauritius Observatory figures. The same Tananarive on Madagascar. Batavia, in Java, displays also an indisputable resemblance to the Arequipa curve. North of the equator, Havana gives a similar curve, whereas the data of San Juan, Porto

Fig. 1.

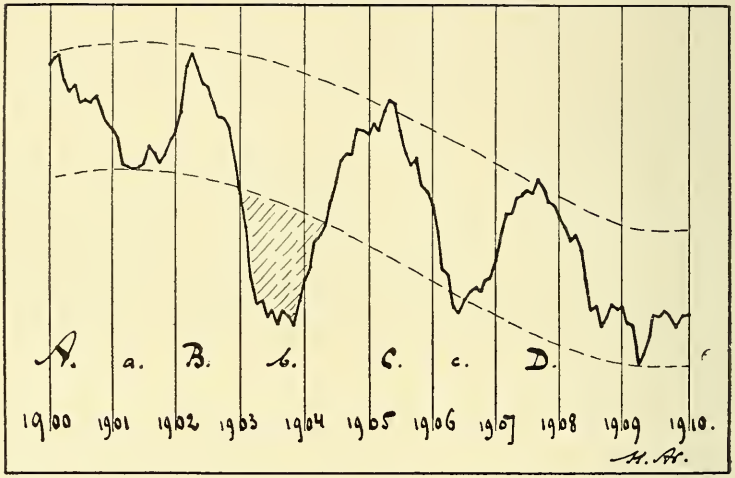


Fig. 1. Curve of the consecutive annual temperatures observed at Arequipa. A, B, C, D : pleionian crests. The meionian depression *b.* may have been accentuated by the effect of volcanic dust produced by the Mt. Pelé eruptions or by other causes. The curves connecting the crests and the depressions demonstrate the existence of a long range variation different from the sunspot frequency variation.

Rico, give a slightly retarded curve. This is a most interesting fact because the pleionian crests of Porto Rico could not be retarded if these temperature anomalies did not have a tendency to persist, combined with a tendency of displacement.

Considering, for the same period of years, consecutive curves for a great number of stations of temperate or even arctic regions, I found that the phenomenon of pleionian variations is less complicated than would be expected, if we only admit that it is a dynamical phenomenon.

The pleions displace themselves as waves. But, as the variations of Havana, Bulawayo, Mauritius, Batavia, etc., are nearly simultaneous, one would be inclined to think that the displacements of pleions go from the equatorial regions towards the poles.

This is not the case. The variation in New York presents most striking coincidences with the Arequipa variation, and the same may be said about the curve of Kazan, in Russia, and North of Iceland, the observations made on Grimsey Isl., under the polar circle, show also all the crests and depressions of the Arequipa curve, slightly retarded.

Therefore, the impulse which produces the pleionian variations must be felt simultaneously all over the world, and

Fig. 2.

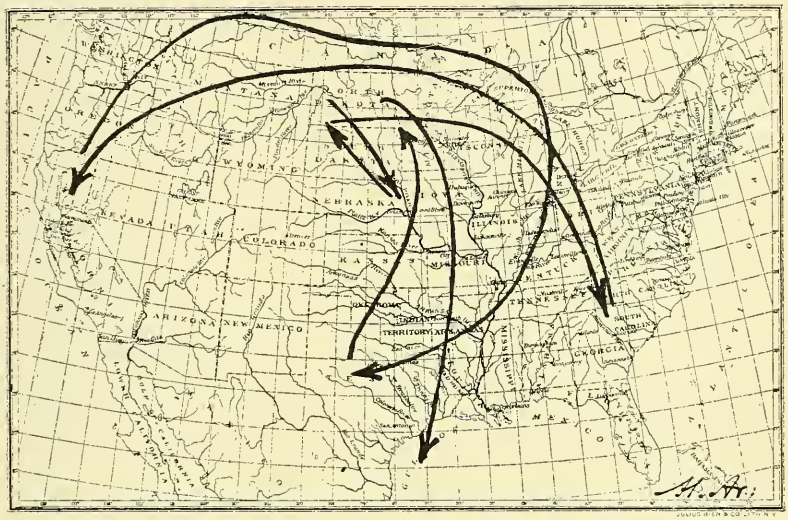


Fig. 2. Pendulations of the pleionian center: 1900–1909.

then,—just as in the case of a handful of stones projected on a quiet surface of water,—from distant points where the impulse is felt directly, the so produced anomalies propagate themselves.

We see now how the conception of thermopleions has to be enlarged. Pleions are not simply the areas occupied by positive departures of temperature and antipleions the areas of negative values. They are thermal waves. It follows that, for practical purposes, it would be best to define a pleion as being the area where the consecutive annual means present a tendency to rise. But then the rise of temperature will be felt all over the area only in the case of stationary pleions. If the pleion displaces itself the rise will be observed on the wave front, whereas on the other side we shall notice a progressive

decrease of temperature. This, of course, applies to consecutive means.

In order to study the displacements of pleions, I made detailed annual departure maps, for the years 1900–1909, for Scandinavia and Central Europe, for North America and for the Atlantic. I hope to publish these maps as well as the discussion of the results obtained and, at present, I will simply mention some of the interesting points of my investigation.

The main result gained by the study of the European maps is that, during the years 1900–1909, the pleions and antipleions did not move from the Atlantic towards Asia. On the contrary: the displacement was from the NE. towards the SW., or from the E. towards the W. Moreover, these displacements did not cross the areas of maritime climate. The big pleionian variations of Europe appear to be a purely continental, and perhaps, arctic phenomenon. But, the areas where they are formed, in situ, are probably not always the same.

For the United States I have utilized, besides the annual detailed departure maps and the consecutive curves of a selection of stations, also consecutive maps obtained from the district means published in the Monthly Weather Review. I will notice a few problems arising from a closer examination of these consecutive maps.

First of all, during the years 1900–1909, the pleions as well as the antipleions displayed a tendency of persistence. No see-saw movement, between a pleion and an antipleion, leading to the gradual disappearance of both and then to the formation in situ of a pleion on the place formerly occupied by the antipleion and vice versa, could be traced. Minor see-saw oscillations took place, but served simply to increase or decrease the contrast between the pleions and antipleions without destroying them. Together with the tendency to persist goes a tendency of displacement. These displacements are generally gradual and continuous, but sometimes they may be very fast and in a striking contrast to the nearly stationary conditions which preceded or followed the rapid change of position.

Another fact is the tendency of the pleions and antipleions to remain on the continent. In other words, the phenomenon of the variation in the distribution of the anomalies of yearly temperatures in North America, is a purely North American phenomenon. The pleions and antipleions seem to be correlated or bound together. One depends on the other. If one moves the other moves. The area of the North American continent seems not to be wide enough for the simultaneous presence of many pleions and antipleions. In order to remain on the continent the motion of a pleion involves a displace-

ment of the antipleion in an opposite direction. A rotatory movement is the consequence. *It is a pendulation* (fig. 2).

The principal problem is, of course: what keeps the pendulation going? Without some exterior impulse the movement would die out or could not even originate. I think that it is the cause of the formation of pleions which, repeating itself more or less periodically, gives the impulse to the clockwork.

The Russian pleions have shown some correlations with the equatorial variation of temperature, illustrated by the consecutive curve of Arequipa. The consecutive curve of New York also belongs to the Arequipa type. We see now how the tendency of the pleions to maintain their existence complicates the problem of their mode of formation or origin.

Because, since for certain parts of the United States the consecutive temperature curves belong to the direct type,—that is to say, are similar and coincide more or less in time with the equatorial curves,—the impulse producing these variations must be the same as that which produces the tropical variations. This impulse is evidently extra-terrestrial. Therefore, where the variation is direct, the departures of temperature will not be due to abnormal conditions of atmospheric circulation, but will, on the contrary, produce such changes of atmospheric pressure, wind direction and velocity, etc., as may be characteristic for either pleions or antipleions.

But on the maps the pleions do not disappear: they move away. Now the question is how—in a direct type of variation—the pleion corresponding to the second crest of the consecutive curve is renewed? Is it the same pleion coming back from the region it was pushed away from by the formation in situ of the direct antipleion, or is it a new pleion, and if so what became of the first one?

Let us call the pleionian crests of the Arequipa curve A, B, C and D (fig. 1). The consecutive maps show that the crest B of New York went northwest over Canada and then southwest towards California. The pleion came back nearly the same way during 1904–1906 (fig. 2). The crest C of New York is therefore the same as B. But if we try to follow this pendulation on the consecutive curves of individual stations we do not succeed very well. And this is because the amplitude of the departures changes independently of the pendulation. The pleions pendulate and surge at the same time. An old pleion may be reintensified. In the case of the pleion C, the surging is nothing but the superposition of a new pleion upon an old one, so that C is the residual of B, plus a new impulse produced in situ under the influence of the direct solar action.

In this way it is conceivable how the pleionian variations may be more important on the North American continent than identical variations in tropical regions.

I have taken the differences between the highest and lowest departure for each of the 109 consecutive maps, in other words, the total amplitudes between pleions and antipleions. From 1900 until 1906 the reversed curve expressing these figures graphically and the Arequipa curve are similar. Then, between 1906 and 1907 an interesting anomaly is noticed. Moreover, the Arequipa temperatures decreased from 1900 to 1909. In the United States the differences between pleions and antipleions were also decreasing during that period of years. Independently of the pendulations, the Arequipa variation affects therefore the entire system of North American pleions and antipleions.

I should like now to pass in review some results obtained from the close examination of European rainfall data, for the years 1851–1905, and to other researches I made on the variations of atmospheric pressure and of sunshine records.

For rainfall and the other meteorological elements the consecutive curves also show perfectly characteristic crests and depressions. Moreover, the rhythms are absolutely similar to those of temperature. In consequence we shall have to speak of pleions of atmospheric pressure or baropleions, or, to use a simpler expression, of baros and antibaros. And likewise, in the case of rainfall, we shall have ombropleions or ombrons and antiombrons. And in the case of sunshine, we shall have to speak of helions and antihelions.

It will be necessary to establish the details of all these variations before it will be possible to search for the mutual relationship of thermopleions, baros, ombrons and helions, and only then will it be possible to examine the rôle of the centers of action of our atmosphere, and this will lead to the study of seasonal anomalies.

It is an immense field of research work to be made, but, as will be seen immediately, all this is only one side of the question of climatic variations. We have indeed to consider also the macropleionian variations.

2. *Macropleionian variations.*

In order to detect these variations it is necessary to form consecutive means of groups of years. It is impossible to take 4, 5, or 6 yearly means because then the chances are that the figures will be greatly influenced by the pleions. To eliminate the pleionian variation it is necessary to take 10 yearly means. But even then some predominant pleions may affect the means. On the other hand, it is impossible to take a longer period than ten years, first of all because it is only exceptionally that we have to deal with long temperature records which may be con-

sidered as being perfectly homogeneous, and then, because a variation of about 18 or 19 years seems to exist.

Utilizing Bigelow's tables of temperature data for the United States, for 1873–1905, I made consecutive means of decades of years and inscribed the departures on maps.

To sum up the results obtained by the inspection of these maps, I will say that the long-range variations of temperature, of particular stations in the United States, are due to irregular pendulations of macropleions and macromeions, that these pendulations are complicated by the existence of slight see-saw movements (or vibrations) which increase or decrease the departures, making the macropleions more or less accentuated, and that, finally, the entire system of macropleions and macromeions moves up and down. This last movement is shown on the maps by an increase in size of the macropleions and a decrease of the macromeions or vice versa. This is the real long range variation. The decade of 1873–1882 is a typical example of a widely spread out macropleion, the decade 1883–1892 shows a predominant macromeion.

For Europe, I also made maps giving the distribution of the percentage of rainfall during the consecutive decades of 1851–1905, and found that the macroombrons display phenomena very similar to those of the thermopleionian variations.

A priori, one may presume that the variations interesting longer periods of years will also pendulate. I do not think that this hypothesis is in contradiction with the results Ellsworth Huntington has obtained from the discussion of historical data. Concerning geological records it would be absolutely premature to express any opinion.

But, for practical purposes, the brachypleionian variations present a greater interest. As yet I have only studied the brachypleions of Arequipa.

3. *Brachypleions of Arequipa.*

For this study I had to take the daily values of temperature most kindly sent to me by Prof. Edw. C. Pickering. I made 5 day or pentade means, and then, consecutive monthly means,—the pentade and not the day being the unit. In this way I noticed that during certain years (1902, 1903, 1906 and 1907 in particular), a brachychronic variation of about 55 days duration, from one maximum to the following maximum, is the most striking feature of the curves (fig. 3).

The amplitudes of these variations may be as important as the amplitudes of the pleionian variations, that is to say, equal the value of the annual variation of temperature.

Conclusion.

The main question is to know what produces these variations of short and of long duration ?

During some volcanic eruptions great quantities of pulver-

Fig. 3.

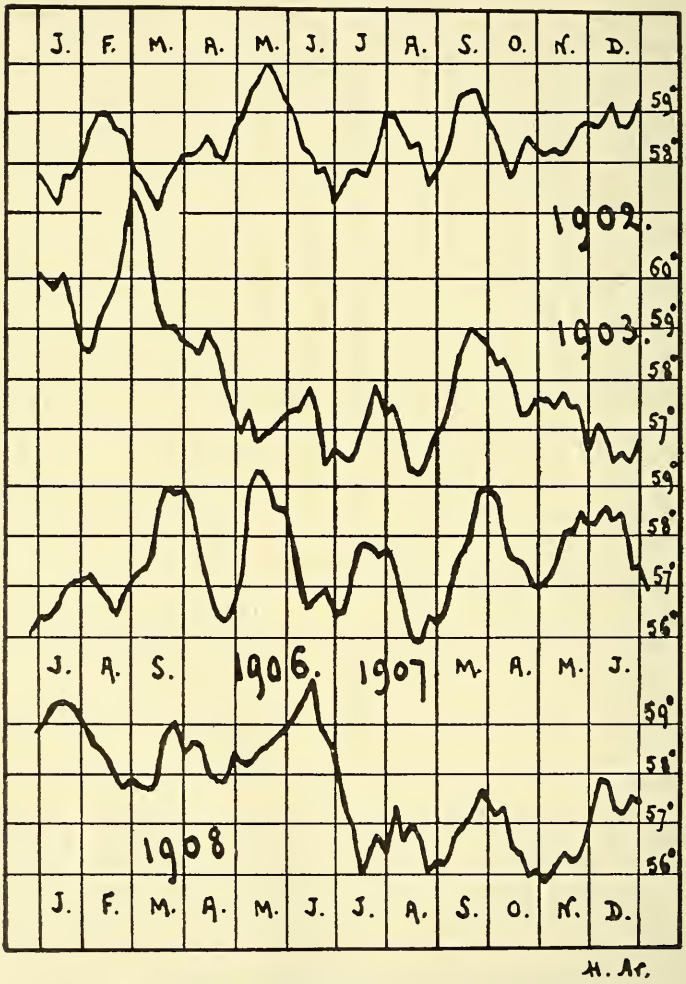


Fig. 3. Brachypleionian variations at Arequipa.

ized ashes have been projected to altitudes higher than the mean elevation of the cirrus clouds. Being above the clouds,

this volcanic dust could not be washed out from the atmosphere, and remained therefore in suspension long enough to be spread out all around the world, by the western drift of the general circulation. Recently, C. G. Abbot has shown that the dust projected by the eruption of Mt. Katmai, on June 6 and 7, 1912, affected the solar constant determinations made by him and Mr. Fowle in Algeria and on Mt. Wilson.

However, the occasional presence of volcanic dust, producing a general haziness of the atmosphere, as in the case of the Krakatoa and Katmai eruptions, in particular, is a very inadequate explanation of the formation of antipleionian depressions of temperature. The consecutive curves prove it very well. The antipleionian depressions, on the curves of tropical stations, reoccur more often than the eruptions producing atmospheric haziness. Besides that, the sedepressions are not V- or U-shaped discontinuities, marking interruptions on a continuous curve, but are preceded and followed by crests. Now, the presence of such crests could not be explained by the volcanic dust hypothesis. All this, supposing of course striking coincidences between the depressions of the equatorial temperature curves and the volcanic eruptions producing dust veils in the higher layers of our atmosphere, which is only exceptionally the case.

The brachypleionian, the pleionian and the macropleionian crests of the consecutive curves demonstrate therefore with evidence the fact that more or less periodical changes of the solar constant must be the real primary cause of the various climatic variations.

Considering the means of the solar constants, observed by Abbot during the summer months of 1905, 1906, 1908, 1909 and 1910, and comparing the differences between the mean values with the corresponding differences of temperature in Arequipa, I arrived at the conclusion that a difference of 1° F. corresponds to a change of 0·01 of the solar constant.

If this is the case, the lowering of temperature required to produce ice age conditions, on our earth surface, could easily be explained by variations of solar activity, in a measure which does not exceed the differences actually observed between the individual values of the solar constant.

Differences of 0·15 to 0·20 have been observed every year. Such differences, if permanent during some centuries or thousands of years, would produce the required differences of temperature.

Hastings-on-Hudson, December 27, 1913.

Art. XXV.—*Late Paleozoic Glaciation in the Boston Basin, Massachusetts;* by Frederic H. Lahee.

The Boston Basin is essentially a down-faulted block of sedimentary rocks and associated lavas which were folded and locally metamorphosed at the close of the Paleozoic Era. They are thought to be of late Carboniferous or of Permian age. As regards the stratigraphic sequence, the "Roxbury conglomerate" constitutes the lower 3000 feet,* and the "Somerville slates" constitute the upper 2300 feet,* of the formation. Where these two groups of strata pass into one another there is a considerable thickness (two or three hundred feet) of transition beds—shales or slates, sandstones, and conglomeratic rocks. The main mass of the Roxbury conglomerate displays characters suggestive of piedmont fluviatile deposition, but within the transition beds are several features which point strongly to Paleozoic glaciation in this vicinity.

In his "Squantum Tillite"†, Mr. R. W. Sayles has ably presented the case for glacial action in the deposition of the upper part of the Roxbury conglomerate. It is this upper portion, belonging to the transition beds, that he calls the Squantum tillite. While Mr. Sayles' paper is written with a force and clearness which should convince, nevertheless there may still be some of his readers who will remain somewhat skeptical. Having some familiarity with the Boston Basin and, at least in the large, strongly favoring Mr. Sayles' convictions, I therefore take this opportunity of offering a few suggestions.

Has not Mr. Sayles used the word *criterion* inadvisedly? On page 144 of his article he lists fifteen characteristics of the Squantum tillite and subsequently refers to these as criteria. The presence of "Some rounded, water-worn pebbles or boulders" is not a criterion for the Squantum tillite nor for any other tillite or till. They do not assist in the determination of a deposit as till or tillite. The same may be said of a few of the other phenomena cited in the list.

Criteria which indicate the action or association of ice in the deposition of any sedimentary series may be classified as follows:—

A. Criteria observed in ice-laid deposits (till and tillite).‡

1. The deposit as a whole,
   (*a*) Is "an unstratified mass of miscellaneous and unsorted rock materials."

* Mansfield, G. R.: The Origin of the Roxbury Conglomerate. Mus. Comp. Zool., Bull., xlix, pp. 209-210, 1906.

† Mus. Comp. Zool., Bull., lvi, pp. 141-175, 1914.

‡ In this classification I have drawn freely from Mr. Sayles' paper.

(*b*) May contain intercalated "nests" and layers which are often contorted.

2. The matrix consists usually of rock-flour (sometimes of sand).
3. The included fragments,
   (*a*) If of compacted (frozen?), but not consolidated, materials (clay or sand) when handled by the ice,
      (1) Are usually angular, and
      (2) May show crumpling, caused by the pressure of superincumbent or moving ice.
   (*b*) If of consolidated rock when handled by the ice,
      (1) Are generally angular or subangular, showing the effects of bevelling on one or more sides and of blunting on one or more corners.
      (2) Are often striated.
      (3) May show concave fractures.

B. Criteria observed in aqueo-glacial deposits.

1. Isolated pebbles and bowlders, striated or not, may be found in beds which, by their fine texture, uniform bedding lamination, or lack of marked cross-bedding, indicate that they were deposited by relatively weak currents or in quiet water. Such pebbles and bowlders suggest ice-rafting.
2. Contemporaneous deformation, due to grounding of floating ice blocks.*

C. Criteria observed in connection with the older formations over which the ice may have passed.

1. Contortion and disruption of mud and sand beds, etc., suggesting that these were unconsolidated or too weak to resist the ice pressure. This phenomenon is generally accompanied by criteria cited under A, 3, (*a*). In this case the surface of unconformity above the older formation is very irregular and shows no striation or other evidence of strong abrasion of this kind.
2. The surface of unconformity is polished, striated, or grooved, and shows other characters typical of ice erosive work. These features suggest that the older formation was consolidated hard rock when the ice passed over it.

Of the criteria noted above, the only ones which are rare or absent in the case of the Squantum tillite are the striated pebbles and the striated subjacent rock floor.

For those who would question the action of ice in the deposition of part of the Boston Basin sediments, the following remarks may be added to what Mr. Sayles has already said :—

(1) Absence of a striated pavement beneath the tillite is to be compared with the relations between the Kansan till and the

* See Lahee, F. H., Contemporaneous Deformation : a Criterion for Aqueo-glacial Sedimentation, Journal of Geology, vol. xxii.

underlying Aftonian stratified drift, as figured by Chamberlin and Salisbury.*

(2) Scarcity of striated pebbles and bowlders in the tillite has been compared by Mr. Sayles to the similar case in the Pleistocene of southern Rhode Island. Last summer (1913), in company with Dr. A. Knopf of the U. S. Geological Survey, I had an opportunity of examining a number of well-defined lateral and frontal moraines which were built by the Pleistocene valley glaciers of the Sierra Nevada in California. We were much impressed by the great scarcity of striated rock fragments in these moraines. In the Boston Basin this feature may be coördinated with the fact that here ice seems to have travelled over unconsolidated sediments instead of over a hard rock floor.

(3) The large angular blocks of slate and shale included in the tillite† resemble the masses of Aftonian gravel inclosed in the Kansan till, as figured by Chamberlin and Salisbury.‡

(4) Mr. Sayles observes that near the top of the tillite, "intercalated stratified beds may be found." I have frequently noted similar beds of sand, some contorted and some not so, in the Pleistocene till of the Boston Basin, both in irregular till sheets (ground moraine) and in drumlins.

(5) Contemporaneous deformation was observed last autumn in Pleistocene sand deposits at Woodland, Mass.§

(6) The presence of isolated pebbles and bowlders was reported in the Cambridge brick clays which are of Pleistocene age.‖

(7) The Somerville slates, at the base of which are found evidences for glacial action, are remarkable for the absence of fossils. It is interesting to note the similar absence of fossils in the Pleistocene brick clays of Cambridge and other localities.¶

* Geology, vol. iii, p. 385, 1906.
† Sayles, op. cit., pp. 143, 149.
‡ Geology, iii, p. 386.
§ Lahee, F. H., op. cit.
‖ Shaler, N. S., Woodworth, J. B., and Marbut, C. F., U. S. G. S., Ann. Rept., 17, Pt. 1, pp. 970 and 990.
¶ Shaler, N. S., etc., op. cit., pp. 993–994.

Massachusetts Institute of Technology, February 10, 1914.

Art. XXVI.—*Note on the Use of the Wilson Tilted Electroscope;* by H. W. Farwell.

In using the tilted electroscope I have frequently been annoyed by the lack of steadiness of the zero of the leaf and have found various causes for the wandering. Of these I will mention one which I have not seen described, although very likely many who have used electroscopes adjusted to a position

Fig. 1.

very near to unstable equilibrium may have had the same trouble.

The wandering which had been ascribed to defective insulation began to show some relation to the deflections of a galvanometer connected with a thermocouple placed near the electroscope case, and on making observations with a 16 c. p. carbon lamp as a heater, the disturbance was soon shown to be due to convection currents inside the electroscope. The possibility of such a source of disturbance had been considered far too remote, but the curve given above shows how distinct is the relation. The lamp in this case was placed a short distance above the thick lead box which contained the electroscope.

The top of the box was fully an inch over the heavy brass case of the electroscope.

The galvanometer, of low resistance, was fairly sensitive, about 10^{-9} amperes, and a resistance of 200 ohms was used in series with the iron-constantin thermocouple. The electroscope leaf was not at its most sensitive position in this particular observation, the whole fluctuation being about the same as would be caused by changing the potential of the leaf by about ·1 volt.

By moving the position of the lamp to the other end of the electroscope case, the leaf was observed to move down as the temperature increased, showing that the direction of the convection currents had been reversed.

It would appear to be most desirable to use suspensions adjusted as is the gold leaf in this case in a fair vacuum, since it is generally necessary to use some sort of lamp to illuminate the background for the leaf.

Columbia University,
Jan. 29, 1914.

ART. XXVII.—*Mammut Americanum in Connecticut;* by CHARLES SCHUCHERT. With a note on the Farmington specimen by RICHARD S. LULL.

[Contributions from the Paleontological Laboratory, Peabody Museum, Yale University, New Haven, Conn., U. S. A.]

Introduction.—The unearthing of good mastodon bones anywhere is worth noting, and when a fine skeleton is found, and especially in Connecticut, the discovery is all the more important. In addition, the latest find can be somewhat directly connected with the vanishing of the Wisconsin ice sheet, the last glacial episode of the Pleistocene. During the past century mastodon bones have been discovered in Connecticut but five times, the last one found preserving more of the skeleton than all the previous ones combined. Sooner or later these occurrences will assist in the formulating of a more detailed history of the Glacial Period, a time as yet unravelled and unmarked by the successive faunas and floras that inhabited North America during this age of decidedly changing climatic conditions. As yet we know but little of this life, and consequently the chronology of the Pleistocene in America thus far depends solely upon the physical characters of the deposits and the topography of the period.

Previous finds.—(1) The earliest record of the finding of mastodon bones in Connecticut dates from previous to 1828, when "some remains of the mammoth were found in Sharon," Litchfield county, near the New York State line.* Nothing more is known of this discovery nor of what has become of the bones.

(2) Silliman states that while excavating the Farmington canal in the summer of 1828 there were found near Cheshire "three or four large molar teeth of the mammoth" in gravel but a few feet under ground. Some of the teeth are said to have been much worn and therefore were of an old animal. It appears that all of them except one were broken up at the time of their excavation, and that the remaining tooth was presented to Yale College by Edward Hitchcock (loc. cit.). This is an uncut second lower molar of *Mammut americanum* (Yale Museum catalogue number 11985). The three crowns are well preserved and but little mineralized, as the tooth was found in a more or less dry gravel.

(3) In 1833, while a canal was being dug for the New Britain Knitting Company in New Britain, through a pond which then covered what is now the corner of Elm and Church

* This Journal, xiv, 187, 1828; also xxvii, 166, 1835.

streets, there was found, according to Silliman, a nearly complete dorsal vertebra of a mastodon. The dorsal process was 17 inches long, the centra 5·5 inches in diameter and nearly 3 inches in thickness, while the neural canal was 3·5 by 2·75 inches in height and breadth respectively. The bone had a dark chocolate color and was "not mineralized in the least." It was taken out of mud or clay 3 feet beneath the surface. Associated with the bone were freshwater shells "of the genera Planorbis, Lymnæa, Cyclas, etc., similar to those occupying the waters of the vicinity."*

Doctor Walter L. Barrows, of Trinity College, directs attention, in a letter to the writer, to the "Connecticut Courant" for June 2, 1834, in which there is a statement that Silliman exhibited this bone at a lecture given at Hartford May 27, 1834. From this account is taken the following: "From the perfect condition of the bone thus accidentally discovered, there is reason to believe that a complete skeleton may be recovered in the morass where the specimen in question was found." This bone was presented to Yale College by Elijah H. Burritt, but is evidently no longer in existence.

(4) A second mastodon was discovered in New Britain in September, 1852, and the bones were for many years on exhibition there at the State Normal School. What became of these bones after 1885 is not known. The present information is taken from an account by Hon. David N. Camp,† entitled "Mastodons roamed Connecticut once." While excavating in a soft swampy soil for a pond on land belonging to Mr. William A. Churchill, the workmen came across a considerable portion of a mastodon skeleton, "the thigh bone, humerus, tibia, several of the ribs, and two or three teeth. Some of the bones, on being exposed to the air, crumbled." This locality is now in the city of New Britain back of the Young Women's Christian Association, or near the junction of School and College streets.

(5) Professor Edward Hitchcock got in 1871 a mastodon molar that was taken "out of a muck bed on the farm of Elias Bardwell" in the town of Colerain, which is near the north line of Massachusetts. This was then the first known occurrence of mastodon in that state.‡

The Farmington or Pope mastodon.—Late in August, 1913, Italian workmen, while digging a trench to drain a small upland swamp on the beautiful estate of the late A. A. Pope, near

* This Journal, xxvii, 165, 1835. Here the locality is given as Berlin, but D. N. Camp, in the article cited, gives it as above described.

† Hartford *Times* of January 3, 1914. The first statement regarding the 1852 specimen appeared in the same paper, on September 21 of that year.

‡ This Journal, (3), iii, 146, 1872.

Farmington, reported to the superintendent, Mr. Allen B. Cook, the finding in the bog of a "black devil." Mr. Cook, a graduate of the Massachusetts Agricultural College, soon saw the significance of the find and reported the matter to Mrs. Pope, who was much interested in the remarkable discovery and through Attorney Charles T. Brooks brought the information to the writer. The trench at the time of the latter's visit revealed a number of large bones of one of the fore limbs and the back part of the skull, which had unfortunately been greatly damaged before the Italians became aware that they were removing bone and not a prostrate tree.

The exhumation of the skeleton was undertaken by Mr. Hugh Gibb, assisted by three other preparators from Peabody Museum at Yale, and by five Italians. So careful were these "bone diggers" that all the clay immediately around the skeleton was dug out with their hands, as they felt their way through the sticky clay down to and around the bones. The greater part of the skeleton was taken out in two weeks' time. Subsequently it was decided to enlarge the shallow hole and to make of it a water reservoir for the estate, and during this excavation the workmen late in November came upon one of the great tusks, lying alone, 23 feet away from the skull, and in perfect preservation.

The skeleton of the Farmington mastodon consists of all of the essential parts, minus most of the small bones of the feet, a few of the smaller leg bones, most of the caudal vertebræ, and one of the tusks. The greater part of the animal lay together with the bones more or less jumbled, but in the main there was still considerable natural skeletal alignment,—the head at one end and the pelvis less than 10 feet away. Scattered about and often many feet away from the central mass lay single bones of the feet, tail, vertebræ, ribs, and one scapula. The recovered tusk lay farthest away and on a level about 2 feet higher than the main mass of bones, which were in the lowest part of the swamp. Fig. 1, drawn to scale by Professor Lull, shows the general disposition of the bones of the mastodon as they were found.

Geologic position of the Farmington mastodon.—The Farmington skeleton lay in a shallow trough directly on bowlder-clay, a thin covering of ground moraine that originally mantled the adjacent hills and valleys alike and was deposited by continental glaciers during Wisconsin time. (See contour map, fig. 2.) The bowlder-clay is light blue in color and consists of a decidedly sandy fine mud, with some coarse sand, an abundance of muscovite, and many striated bowlders, large and small, mainly of trap with some quartzite and crystalline rocks. That the till was largely derived from the adjacent Triassic

area is attested not only by the sandy blue clay but more especially by the abundance of trap bowlders.

The Farmington highlands had not become much covered

Fig. 1.

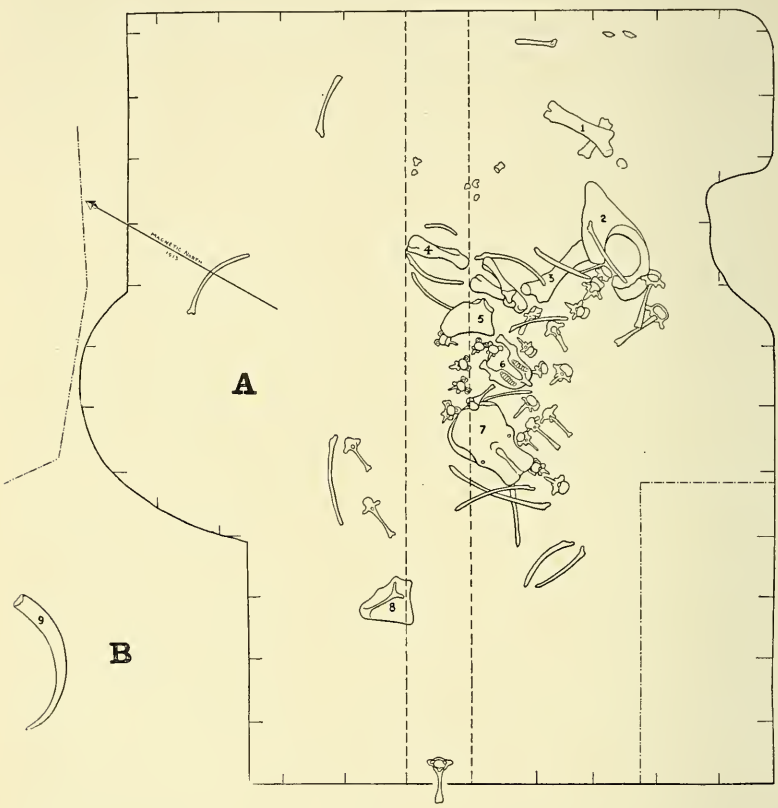
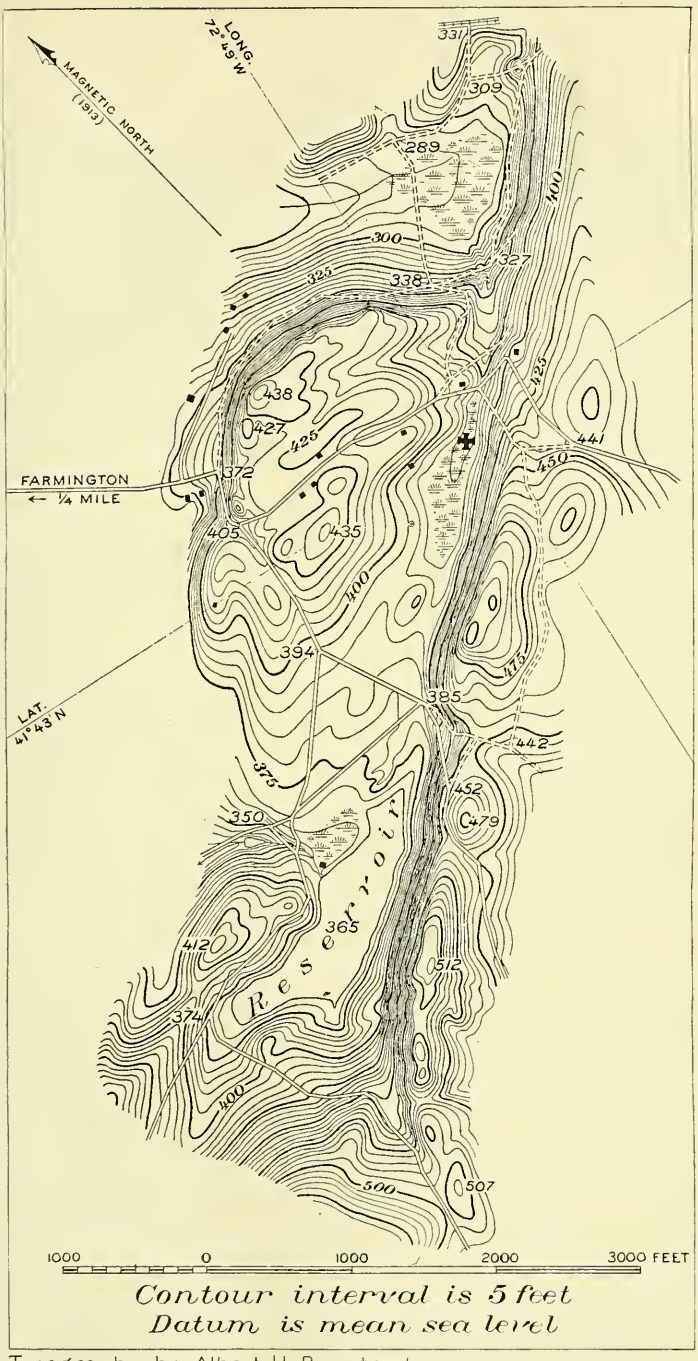


Fig. 1. Diagram of the Farmington swamp, showing the bones *in situ* and the trench that led to their discovery. Drawn *in absentia*, from descriptions, sketches, and photographs, by Richard S. Lull. Approximate scale 1/8 inch to 1 foot.

A. Original excavation. B. Subsequent excavation in part. 1, femur; 2, pelvis; 3, femur; 4, humerus; 5, left scapula; 6, lower jaw; 7, skull; 8, right scapula; 9, tusk.

with vegetation when the proboscidean under discussion died, for not a trace of organic matter or of oxidized till was found beneath the skeleton, and but very little vegetable matter is seen in the slightly modified or oxidized bowlderless clay surround-

FIG. 2.



Topography by Albert H Bumstead

FIG. 2. Contour map showing the topography of the land where the Pope mastodon was found (+). The sharp ridge is made up of Triassic trap. Drawn by Albert H. Bumstead, through the kindness of Professor Hiram Bingham.

ing the bones, nor was there a trace of the organic matter of the animal left (see fig. 3). Further, there was no permanent lake with an abundance of vegetation formed at this time or later, for no freshwater shells (shell marl) were seen and the clays do not at all effervesce under hydrochloric acid. Carbonate of lime is a good preservative of bones, but in this case there is none present. The animal does not appear to have been mired where it was found; it probably died and lay decomposing in the marsh, where occasional carnivorous or scavenging animals came and dragged about some of the bones, though why one of the tusks should be about 23 feet away from the skull and on higher ground by 2 feet is hard to explain. On the other hand, the body could not have lain thus exposed many years, even in a cold climate, for most of the bones immediately above the till have well-preserved smooth and glossy surfaces. Nevertheless, nearly all of the skeleton of the feet is absent, while some of the other small bones, and especially those of the tail, were so rotten that they could not be lifted and preserved. The absence of these smaller bones may be due either to carnivores or to oxidation, or to both causes. Some of the parts, and especially the pelvis and top of the skull, lay so near the turf that the percolating waters with their humic acids and the penetrating roots of the plants had done considerable damage. It would seem, however, that the skeleton must have soon become buried, and this is suggested by the embedding clay, which is almost unaltered glacial till devoid of all bowlders. In other words, the clay of the general ground moraine on either side of the little valley, but more particularly that of the rounded hills to the north, was then being washed from between the bowlders into the lower land, rapidly covering the skeleton. These hills are even now covered in abundance with the much oxidized trap erratics, hardly any of which retain the glacial striations, but there is little blue clay here now. We therefore have the phenomenon of the unoxidized clay washed into the swamp or seasonal lake, while the remaining bowlders have ever since been exposed to the influences of the weather, the trap bowlders being the most altered.

Above the till wherein the mastodon lay follows from 6 to 18 inches of glacial blue bowlderless clay that is but slightly modified by some plant remains, largely roots, that have penetrated into it from the swamp above. This is followed by 30 inches of a similar clay, slightly more modified by entombed plants and penetrating roots, but still with an abundance of brilliant muscovite. At the top occurs about 18 inches of stringy turf that is full of water during most of the year, making the swampy ground. In other words, the Farmington

FIG. 3.

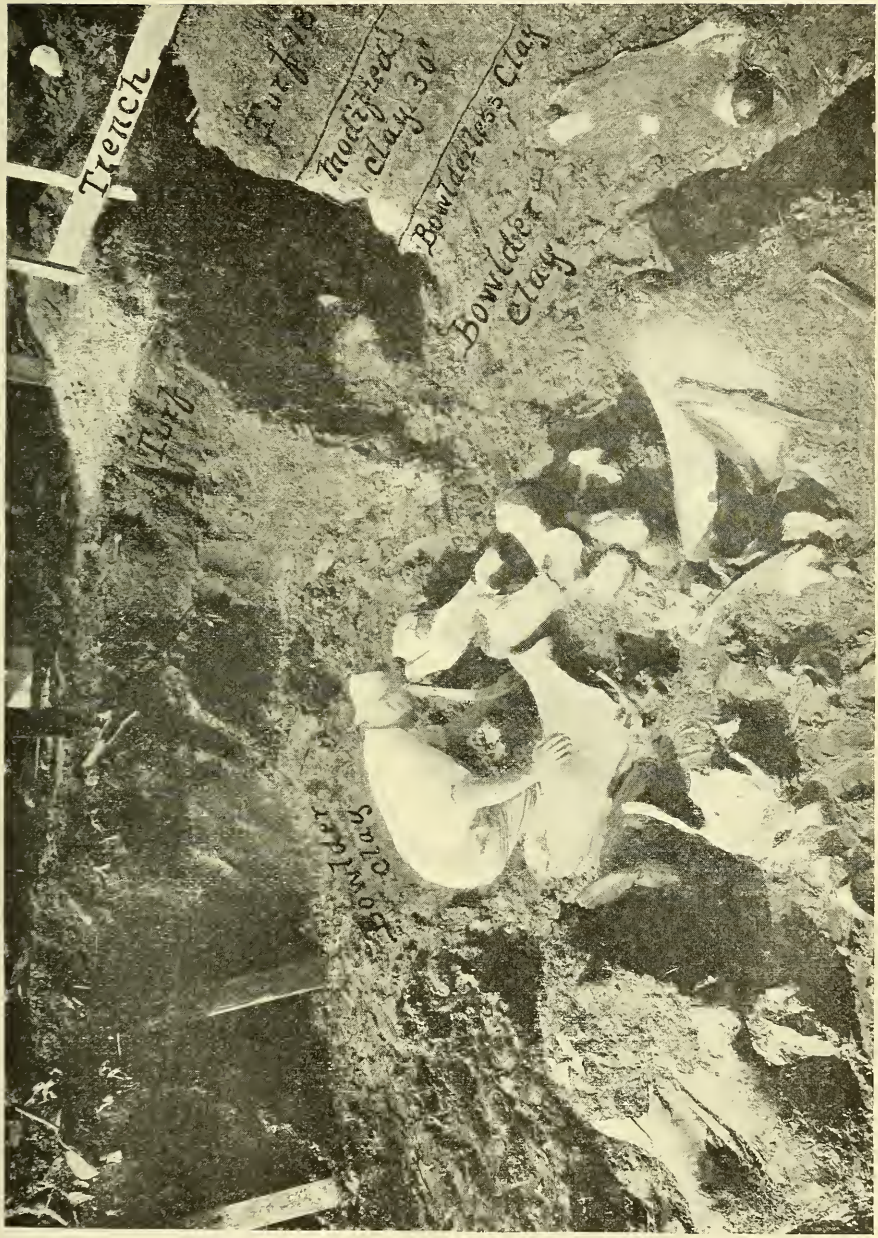


FIG. 3. Photograph of the diggings after the skeleton was uncovered. The animal lay on the bowlder-clay. Photograph by A. J. Tefft.

mastodon was covered in the course of time by 5 feet of ground, 4 feet of which is modified glacial clay. The animal was therefore buried by the inwash of about 4 feet of glacial clay, since which time about 18 inches of turf has accumulated.

As the skeleton was entombed shortly after the vanishing of the Wisconsin ice sheet in the highlands about Farmington, one gets from the evidence given a hint of the recentness of these two sets of phenomena. The washing of the clay into the depression could have occurred in a few hundred years, and the stringy turf apparently did not take much more time to form. Then, too, the skeleton shows no mineralization nor petrifaction and is but little discolored to a light brown by the waters of the swamp. Further, the several skeletons found about Newburgh, New York (chiefly the Warren skeleton of the American Museum of Natural History and the Otisville specimen at Yale) look like bones buried but a few hundred years. Both of these mastodons were buried in a shell marl, a preservative of bones, but still not a single shell species of which the marl is composed is extinct, according to the great conchologist Gould (who identified *Limnea galbana*, *Planorbis parvus*, *Valvata tricarinata*, *Amnicola galbana*, and *Cyclas galbana*). The Warren mastodon lay in the marl of a small pond not over 40 feet in diameter, covered by a foot of red moss and 2 feet of peat bog. The entire skeleton lay in articulate position and was so well preserved that it was dug out by inexperienced men in two days. Furthermore, between the ribs lay from 4 to 6 bushels of vegetable food, largely coniferous and much like spruce or hemlock.

Did man and Mammut americanum live together in America?—Can it be that *Mammut americanum* vanished from Connecticut within a thousand or at most a few thousand years and yet was unknown to the North American Indians? If the prehistoric Indians knew and helped to exterminate these animals, and as they were the makers of neolithic implements, why do we not find ivory in their graves?

In this connection it should not be forgotten that John M. Clarke in 1887 dug up at Attica, Wyoming county, New York, bones of *Mammut americanum* associated with pottery and charcoal. Not much of the skeleton was present and the bones lay but 2·5 feet beneath the "natural surface." Associated with them (ribs) were "four small fragments of charcoal" while in another part of the diggings beneath all (4 feet) of the vegetable muck and lying upon "compact laminated clay" "was found a fragment of pottery, and from beneath and around it were taken about thirty fragments of thoroughly burned charcoal. These traces of ancient man were found fully 12 inches further down from the natural surface of the ground

than the deepest of the bones taken from the other [there were two] sink-hole." The pottery indicated a thick coarse vessel about 8 inches across, while the "thoroughly burned" charcoal varied in size "from two inches in diameter down."*

All in all, the evidence appears to show that the Wisconsin ice sheet vanished from Connecticut and New York not many thousands of years ago. Further, the associated human evidence found with or beneath the Attica mastodon bones is a positive hint that should open our minds to the possibility that man was associated in America with *Mammut americanum*. There is still further paleontologic evidence suggesting the existence of man even earlier than the occurrence in New York. Professor Williston states that on a small tributary of the Smoky Hill river in Logan county, Kansas, Mr. Handel T. Martin found beneath but in contact with a right scapula of the extinct *Bison occidentalis* an arrowhead. The bones of the eight animals present and the human implement were not surface finds, but were secured by digging away several feet of the "upland marl," a deposit that originally covered the fossils at least to a depth of 20 feet. In this marl also occurs *Elephas primigenius*, an animal well known to ancient man of western Europe.†

Note on the Farmington specimen; by Richard S. Lull.

The Farmington mastodon has not yet been prepared for exhibition, so that two important elements, the skull and pelvis, being still in the plaster of Paris bandages which were put on at the time of exhumation, are unavailable for study. Certain broad generalizations can, however, be made which may be of interest.

The skeleton is that of a fully adult individual, the evidence for which lies in the great size, the fully coössified epiphyses of the vertebræ, and in the facts that the full quota of molars had come into use and that all of their ridges show signs of wear; though, as the more posterior ones have suffered but little in this regard, the animal must have been in the prime of life. I should judge the specimen to have been a male, though the one absolutely diagnostic character, that of the presence of one or two lower tusks as in the great Warren mastodon in the American Museum of Natural History, is lacking. The size again and the great development of the upper tusks are the only present evidences of sex available, though that of the ratio of pelvic aperture to pelvic breadth, larger in the female, may be learned when the element can be studied.

* Forty-first Ann. Rept., N. Y. State Mus. Nat. Hist., 1888, 388–390.
† Amer. Geol., xxx, 313-315, 1902.

The limb bones are relatively slender in proportion to their length in comparison with those of the Warren mastodon or the Otisville specimen mounted at Yale, both of which are exceptionally powerful animals though differing markedly in stature and general appearance. In size, the new skeleton stands almost midway between them; for instance, the ulna of the forearm measures 28 inches in length in the Otisville animal, 31 inches in that of Farmington, and 34 inches in the Warren specimen, and the other measurements which I have been able to compare run in much the same proportion.

The Otisville specimen was not fully mature at the time of its death, as certain of the vertebral epiphyses are still but partially coalesced and the hinder ridges of the teeth show no appreciable signs of wear. As mounted, this specimen, a young male of abundant promise, stands 8 feet 2 inches at the shoulder, with a length of 13 feet 2 inches from the tip of the premaxillary bone to the curve of the tail. The assembled bones of the Connecticut specimen, however, give an estimated shoulder height at least 6 inches greater, though just how the other dimensions would compare one cannot say; but the contrast of bone proportions seems to indicate that those of the entire body would vary as well. The erection of the two skeletons side by side for comparison would thus be of the highest scientific importance.

The tusks of the Otisville mastodon have not been found and little idea of the relative length of this element can be obtained. The size of the tusk socket would indicate a tusk but a half-inch less in circumference than that recently found at Farmington. The latter is 23 inches in greatest girth and measures 8 feet 10 inches on the curve and 6 feet 3 inches between perpendiculars.

There is nothing to indicate that the Farmington mastodon does not belong to the principal Pleistocene species, *Mammut (Mastodon) americanum*, the known range of whose variations is amply sufficient to account for all of the points of contrast which have been mentioned.

Art. XXVIII.—*On the Hydrolysis of Esters of Substituted Aliphatic Acids;* by E. W. Dean.

[Contributions from the Kent Chemical Laboratory of Yale Univ.—cclvi.]

7. *Hydrolysis in Acid and in Alkaline Solution of Ethyl Esters of Hydroxy Butyric Acids.*

Acid Hydrolysis.

Preliminary Discussion.

The effect of the hydroxyl group upon the velocity of acid hydrolysis has been shown* to be somewhat irregular in the cases of acids of the acetic and propionic series. Ethyl glycollate is decomposed a little more rapidly than the acetate. Ethyl lactate, the alpha hydroxy propionate, has a greater reaction velocity at twenty-five degrees and a less at forty-five than has ethyl propionate. This is due to the lower temperature coefficient of the hydroxy ester, but makes it immediately impossible to state that the presence of this particular substituted group facilitates the hydrolytic cleavage. Ethyl glycerate, which is the alpha, beta, di-hydroxy propionate, has relatively a very low rate of hydrolysis, showing that the substitution of two groups may produce an effect differing in order of magnitude from that of one.

In view of the above facts it was thought desirable to obtain more data bearing upon this subject, and consequently measurements have been made of the rates of decomposition of several hydroxy butyric esters. Those which were examined comprise the following list:

Ethyl alpha hydroxy-butyrate, $CH_3CH_2CH(OH)COOC_2H_5$,
Ethyl beta hydroxy-butyrate, $CH_3CH(OH)CH_2COOC_2H_5$, and
Ethyl alpha hydroxy-iso-butyrate, $\begin{matrix}CH_3\\CH_3\end{matrix}\!\!>\!C(OH)COOC_2H_5$.

Ethyl normal butyrate and ethyl iso-butyrate were of course hydrolyzed at the same time with these esters in order that the comparisons made should deal with the results of measurements made under identical conditions.

Preparation of the Esters.

Ethyl butyrate was the Kahlbaum preparation of commerce which was carefully purified by washing and by fractional distillation. Boiling point, 118·5° to 119·5°. The figure given in Beilstein is 119·9°.

Ethyl iso-butyrate was prepared by the method of Pierre and

* This Journal, xxxiv, 293; xxxv, 486.

Puchot.* Iso-butyl alcohol was oxidized with chromic acid and the iso-butyl ester of iso-butyric acid thus formed. From this the ethyl ester was obtained by the successive processes of saponification by alkali, acidification, and treatment with ethyl alcohol. This last esterification was conducted according to the method of Wislicenus.† The purified product boiled at 110°, which is the figure given in the literature.

Ethyl alpha hydroxy-butyrate was obtained by the esterification of acid purchased from Kahlbaum. After obtaining unsatisfactory results from trials by most of the usual methods the method of Bogojawlensky and Narbut‡ was found to be well adapted to this case. The acid was boiled with absolute alcohol in the presence of finely powdered anhydrous copper sulphate. The resulting ester was purified by fractional distillation and a sample obtained boiling between 162° and 164° uncorrected. The temperature given in Beilstein is 165° corrected.

Ethyl beta hydroxy-butyrate was purchased from Kahlbaum and was used without special purification. Its boiling point was 178° to 180° uncorrected; no value is given in Beilstein. As a check upon the reliability of this commercial product a small quantity was prepared by esterifying some of the free acid by the copper sulphate method. One or two portions of this, when hydrolyzed, gave constants approximately the same as those of the Kahlbaum preparation. The freedom of the latter from impurities of any other esters was also proven by the regularity of its velocity constants. The presence of another ester having a different rate of reaction would have caused a progressive decrease in any series of these constants.

Ethyl alpha hydroxy-iso-butyrate was also purchased from Kahlbaum and was proven sufficiently pure by analysis and by determination of its boiling point. The latter was 146° uncorrected, that given in Beilstein is 150° corrected.

Procedure.

The unsubstituted esters of this list have rather low solubilities, so that it was found desirable to modify somewhat the procedure‖ which had been used for acetates and propionates. In cases where a solution of the ester six hundredths or more normal can be prepared in decinormal hydrochloric acid, it is simplest to titrate twenty-five cubic centimeter portions directly

* Anal. de Chim. et Phys., (4), xxviii, 366.

† Ann. d. Chem. u. Pharm., clxiv, 181.

‡ Ber. xxxviii, 3344. See also Clemmenson and Heitman, Am. Chem. Jour., xlii, 319.

‖ This Journal, xxxiv, 293; xxxv, 486.

with approximately tenth normal baryta water. The initial titration will then be about twenty-five cubic centimeters, the final at least fifteen cubic centimeters greater. With a range of this magnitude the constant error of titration does not cause undue irregularity among the constants obtained. Saturated solutions of ethyl butyrate or ethyl iso-butyrate (in decinormal hydrochloric acid) are only two to three hundredths normal, and the range in the titrations, measured in tenth normal barium hydroxide solution, is from five to seven and a half cubic centimeters. This is inconveniently small, and three modifications have been tried to increase it. First, fifteen cubic centimeter portions were titrated with twentieth normal alkali. The advantage here is slight but definite, the range increasing by one-fifth and the error remaining about the same.

Next, a modification of the method of De Hemptinne was tried.* A twenty-five cubic centimeter portion of the reaction mixture was treated with twenty-five cubic centimeters of tenth normal baryta water and the titration completed with a twentieth normal solution of the same alkali. This doubles the range, but unfortunately largely increases the error of titration.

The third and most satisfactory method involved the use of twentieth normal alkali and a hundred cubic centimeter burette. The latter was of the bore of the ordinary fifty cubic centimeter burette but was made with a top bulb that brought its capacity up to a hundred cubic centimeters. When twenty-five cubic centimeter portions of the reacting mixture were titrated with this it was possible to have a total range of from ten to fifteen cubic centimeters with a very slight increase in the error. One drop of twentieth normal alkali was sufficient to produce a perfectly definite color change in the indicator, and there was little increase of error due to the draining and reading of this burette.

The procedure may be briefly summarized as follows: Two hundred and fifty cubic centimeter flasks containing the solutions of the esters in decinormal hydrochloric acid were placed in an accurately regulated thermostat.† At measured intervals of time portions were removed by means of a twenty-five cubic centimeter pipette, run into cold water and their acidity determined by titration with twentieth normal barium hydroxide solution. Phenolphthalein was employed as an indicator.

Of the more insoluble esters, saturated solutions were prepared by shaking the acid vigorously with an excess of ester and then filtering. The paper was first moistened with the acid solution, which prevented the passage through it of any of the undissolved ester. The measurements of the final acidity were made upon portions ef the mixtures, heated several days

* Zeitschr. f. phys. Chem., xiii, 561.
† This Journal, xxx, 72.

in sealed tubes at about ninety degrees. The completion of the reaction was in this way assured.

Calculations were made by the use of the well-known titration formula* for reactions of the first order. In the tables are given values of the constants obtained and of the periods in minutes over which the courses of the various reactions were followed. Bracketed constants are not counted in the averages; their irregularity being undoubtedly caused by undue experimental error.

TABLE I.

Hydrolysis at 25°. N/10 HCl.

Ester	Ethyl Butyrate	Ethyl Iso-butyrate	Ethyl α-Oxy-butyrate	Ethyl α-Oxy-Iso-butyrate	Ethyl β-Oxy-butyrate
Time	3675	3675	4320	3675	3675
	53·3	40·5	37·2	19·9	10·2
	51·8	39·4	40·1	21·3	11·3
	49·2	40·2	40·4	20·4	11·0
	50·3	39·6	40·7	21·3	10·7
10^5K	53·6	39·7	40·8	22·0	10·7
	55·5	39·4	40·7	21·8	10·7
	54·8	40·0	39·5	21·9	10·8
Average	52·6	39·8	39·9	21·2	10·8
Average (duplicate)	51·7	40·0	----	20·7	10·6
Hydrolysis at 35°.					
Time	2280	2940	1920	3000	5700
	107·	92·7	86·3	50·9	28·6
	108·	89·7	86·5	51·7	27·8
	109·	89·1	88.5	52·3	28·5
10^5K	110·	93·3	87·2	51·7	27·6
	112·	91·4	84·8	51·4	27·4
	111·	94·1	88·8	51·3	27·3
	(117·)	92·3	(82·3)	51·2	27·4
Average	110·	91·8	87·0	51·5	27·8
Average (duplicate)	109.	90·9	----	50·9	27·4
Hydrolysis at 45°.					
Time	840	840	720	1560	1560
	248·	205·	203·	113·	61·7
	245·	204·	201·	109·	67·4
	243·	209·	203·	115·	64·2
10^5K	240·	206·	198·	114·	64·1
	238·	205·	192·	116·	64·0
	234·	201·	186·	115·	63·5
	230·	(192.)	182·	113·	62·7
Average	239·	205·	195·	113·	63·9
Average (duplicate)	234·	201·	----	111·	64·1

*This Journal, xxxiii, 27.

Discussion of Results.

Perhaps the most noticeable fact set forth by the above figures is the marked and varying retardation caused by the hydroxyl group in esters of this series. The irregularity in effect of this group was indicated in the previous experiments with acetates and propionates and is now definitely established. The comparison of velocities of corresponding hydroxy and unsubstituted esters shows that the hydroxyl group may produce effects varying in different cases from a slight acceleration to a considerable retardation. Thus it seems to be definitely proven that the effect of the hydroxyl group upon the velocity of ester hydrolysis is not in any sense an additive property.

A second fact of interest is that substituted and unsubstituted iso-butyrates decompose more slowly than the corresponding normal esters. The difference here measured appears to be somewhat greater than that found by De Hemptinne* between the unsubstituted esters but is in the same direction.

The beta hydroxy ester hydrolyzes more slowly than the alpha, which is in accord with the rule indicated by all previous experiments.†

All the esters decompose more slowly than analogous ones of the propionic and acetic series. Temperature coefficients seem to be rather irregular, perhaps on account of experimental error. There are at least no conclusions to be drawn from their variations.

Alkaline Hydrolysis.

In connection with the experiments recorded in the first half of this paper it was thought desirable to make measurements upon the reaction velocities of esters of the above list in alkaline solution. Previous work* has indicated that this velocity is controlled by the strength of the acid from which the ester is derived and by another factor called steric influence. No mathematical relation for the latter has yet been worked out, but it seems to be closely related to that which controls the velocity of acid hydrolysis. The strength of the acid in the latter case has at most only a minor influence.

Procedure.

Part of the measurements were made by the use of the titration method which has been carefully described in an earlier paper‡ of this series. Experiments were also made by a modi-

* Loc. cit.
† This Journal, xxxiv, 69; xxxv, 486.
‡ This Journal, xxxv, 605.

fication of the conductivity method of Walker* which has been employed in the experiments of Findlay and Hickmans† on the velocities of saponification of esters of hydroxy and alkyloxy acids. The modification devised by the author simply adapts the excellent procedure recommended by Walker to the cases of the somewhat insoluble esters here examined. This procedure was in outline as follows:

Fiftieth normal solutions of carbonate-free sodium hydroxide and of ester were first prepared. The conductivity apparatus was of the usual form with a cell of the narrow Ostwald type. The constant temperature bath was a mixture of cracked ice and water which was vigorously and efficiently agitated with a spiral stirrer operated by an electric motor. The initial conductivity was obtained by measurements made on hundredth normal sodium hydroxide solution. The cell was then carefully rinsed and dried. For the actual hydrolysis fifty cubic centimeters of the fiftieth normal alkali solution were placed in a clean and dry Erlenmeyer flask and suspended in the ice bath. The fiftieth normal ester solution was likewise cooled down to zero degrees in the same bath.

At the proper time fifty cubic centimeters of the latter were removed from its container by means of a pipette, run into the alkali and the mixture vigorously shaken for a second or two. The time at which the pipette was half empty was recorded as beginning the reaction. As soon as was convenient a portion of the reaction mixture was transferred from the flask to the conductivity cell and bridge readings were taken at appropriate intervals of time. The flask containing the remainder of the reacting mixture was tightly corked and warmed in a water bath for an hour or so to bring the action to completion. After this it was re-cooled and measurements made upon portions of its contents to obtain the final conductivity. Calculations were made in the same way as those of Walker except that his scheme for their simplification was not adopted. During all the measurements a constant resistance of two hundred ohms was kept in the box, thus eliminating the possibility of slight errors due to this source.

A trial experiment with ethyl glycollate showed that the results obtained checked almost exactly with those of the titration method. Measurements were made with the esters of alpha hydroxy-iso-butyric acid and of beta hydroxy-butyric acid. The constants recorded for the other three esters are from the results of titration experiments.

In Table II are values of the constants obtained and the time periods in minutes over which the reactions were followed.

* Proc. Royal Soc., Series A, lxxviii, 155, (1908).
† Jour. Chem. Soc., lxxxvii, 747.

TABLE II.

Hydrolysis at 0°			N/101 NaOH		
Ester	Ethyl Butyrate	Ethyl Iso-butyrate	Ethyl *α*-Oxy-butyrate	Ethyl *α*-, Oxy-iso-butyrate	Ethyl *β*-Oxy-butyrate
Time	160	185	50	130	120
	·79	(·75)	6·7	1·5	2·5
	·67	·48	6·3	1·8	2·2
	·68	·46	7·1	1·7	2·1
	·65	·46	5·4	1·6	1·9
	·62	·45	6·4	1·6	1·9
		·46	5·8	1·6	1·9
		·45	5·7	1·6	
		·49		1·7	
Average	·68	·46	6·2	1·6	2·1
Average (duplicate)	·71	·47	6·5	1·7	2·0

Table III gives a summary of results from Tables I and II and has in addition some values of affinity constants of acids taken from tables of Landolt, Börnstein & Roth (fourth edition). Figures for ethyl acetate and for ethyl propionate are also tabulated for purposes of comparison.

TABLE III. SUMMARY.

	Acid hydrolysis			Temp. Coefficients		Alkaline hydrolysis	
Ester	10^5K 25°	10^5K 35°	10^5K 45°	25°–35°	35°–45°	K (0°)	(10^5)k(aff) (25°)
Ethyl butyrate	52·1	110·	237	2·09	2·17	·68	1·49
Ethyl iso-butyrate	39·9	91·4	203	2·31	2·23	·46	1·44
Ethyl *α*-oxy-butyrate	39·8	87·0	195·	2·18	2·24	6·2	....
Ethyl oxy-iso-butyrate	21·0	51·2	112·	2·43	2·19	1·6	10·6
Ethyl *β*-oxy-butyrate	10·7	27·6	64·0	2·57	2·33	2·1	....
Ethyl acetate	64·7	163	374·	2·51	2·29	1·2	1·8
Ethyl propionate	71·6	179	406	2·50	2·26	1·1	1·34

SUMMARY.

I. When hydrolyzed in acid solution three hydroxy-butyrates were found to have considerably smaller velocities of reaction than the esters of the acids from which they were derived.

II. Ethyl iso-butyrate decomposes more slowly than the ester of the normal acid ; a difference in the same direction but of greater magnitude occurs with the corresponding alpha hydroxy esters.

III. Ethyl beta-hydroxy-butyrate decomposes more slowly than the alpha ester.

IV. Esters of the butyric acid series appear in general to decompose more slowly than propionates and acetates.

V. The effect of the hydroxyl group upon the velocity of acid hydrolysis is not an additive property.

VI. The velocities of saponification, measured in centinormal sodium hydroxide at zero degrees, vary in the following order with the numerical values representing approximate ratios :

Ethyl alpha hydroxy-butyrate (13·5), ethyl beta-hydroxy-butyrate (4·5), ethyl alpha-hydroxy-iso-butyrate (3·4), ethyl butyrate (1·5) and ethyl iso-butyrate (1·0).

The author wishes to acknowledge his indebtedness to Professors W. A. Drushel and R. G. Van Name for the assistance and advice they have so kindly given during these experiments.

ART. XXIX.—*On Solid Solution in Minerals. V. The Isomorphism between Calcite and Dolomite;* by H. W. FOOTE and W. M. BRADLEY.

SOLUTIONS of liquids in liquids may, as is well known, conveniently be divided into two classes depending on whether there is complete or incomplete miscibility in all proportions. In the same way, it is convenient to distinguish two classes of isomorphous mixtures or solid solutions. In one class, isomorphism is complete and solid solutions in any proportions are possible, while in the other, each solid can take up but a limited amount of the other. The alums form solid solutions of the first class, and among minerals, anorthite and albite are similarly capable of mixing in all proportions, forming the plagioclase feldspars. A large number of salts form solid solutions of the second class, each salt taking up only a limited amount of the other, and among minerals, calcite and dolomite belong in this class. In the present investigation, we have endeavored to determine, at least approximately, to what extent solid solution may take place between these two minerals as they occur in nature.

It will be well to consider first the possible effect of temperature on the mixing limits. This influence has very commonly been disregarded in determining to what extent solid solution may take place. For instance, Retgers* has determined the mixing limits of a large number of salts and has considered the results as representing fixed values without regard to temperature. Van't Hoff,† however, pointed out that the mixing limits of solid solutions, like the composition of partially miscible liquids, should be a function of the temperature and this has been demonstrated experimentally in a number of cases. The determination of mixing limits might, therefore, have little significance unless the temperature were known. However, if the solubility of one solid in another is slight, temperature will have but little influence on the absolute amount dissolved and the mixing limit should be reasonably constant. This is the case, as will be seen below, with calcite saturated with dolomite (or magnesium carbonate). When a solid dissolves a considerable quantity of another, temperature may affect the limit largely and in general a greater absolute change would be expected than where the solubility is slight.

It is evident that for a given temperature each solid will take up the maximum amount of the other when both are

* A series of eleven articles, Zeitschr. phys. Chem., 1889–1895.
† Vorlesungen über Chemie, I, 49.

deposited simultaneously. This is the case, for instance, when solid solutions crystallize as eutectics. If dolomite and calcite could be obtained which had crystallized simultaneously from solution, this material would therefore be ideal for determining the mixing limits of both minerals. A very careful search through the extensive Brush collection has shown no specimen where this condition of affairs was realized, nor have we been able to obtain such a specimen from other sources. This was not unexpected, for it can be shown that at a given temperature, both minerals could be deposited only when the ratio of lime to magnesia in the solution has one fixed value. On the other hand, dolomite or calcite alone could be formed from an infinite number of solutions, with varying proportions of lime and magnesia. Almost the only chance of obtaining such specimens appears to be from the concentration of a large quantity of solution containing salts of both metals, in which case, one mineral would first crystallize to be followed ultimately by the crystallization of both.

There appears to be another way, however, in which crystals of one of the minerals may be obtained saturated with the other. If, for instance, a solution capable of depositing dolomite comes in thorough contact with calcite, the solution should become saturated with the latter and the dolomite resulting should contain the maximum amount of calcium carbonate. A specimen of dolomite, therefore, deposited on calcite, or of calcite on dolomite, may usually be expected to contain the maximum amount of the other salt in solid solution. On the other hand, the calcite or dolomite originally present would not, of necessity, be changed in composition to the limiting value. As will be seen below, one specimen of calcite deposited on a dolomite was apparently not saturated with the latter. In this case, the calcite crystal stood out from the mass of dolomite and the solution from which it formed was probably not saturated with the latter. In general, where the secondary mineral crystallizes in intimate contact with the primary one, the composition should approach closely to the limiting value.

A number of specimens have been obtained showing the associations mentioned above, where either dolomite or calcite has been deposited on the other, and in each case the secondary mineral has been analyzed. In some cases, the material required for analysis was so closely associated with the primary mineral that separation by means of heavy solution was necessary. In the case of one dolomite, No. III, the material was put through the heavy solution twice to remove particles of calcite carried down in the first treatment. Where the specific gravity of the samples is not given in the table, the material was in such good crystals that it could be separated in pure

condition by careful picking. The analyses were made by the usual methods. All the minerals dissolved completely in hydrochloric acid. Iron and manganese were both precipitated by means of bromine and ammonia. Ordinarily, manganese and iron were not both present in appreciable amount and the precipitate, after ignition, was considered either as Fe_2O_3 or Mn_3O_4. In the one case necessary, they were separated by the basic acetate method. Calcium was weighed as oxide after a double precipitation as oxalate. We were able to confirm the observation made by Gooch and Austin* and others that magnesia gives high results when precipitated from a cold solution as ammonium magnesium phosphate in the usual manner. On this account, the precipitate, after standing, was filtered and redissolved in hydrochloric or nitric acid. The solution was heated to boiling, and after adding a small amount of ammonium phosphate, was again made alkaline with ammonia. The precipitate was allowed to stand until cold before filtering. Carbon dioxide was not determined directly.

Calcite.

The specimens used for analysis were the following:

1. Small yellowish scalenohedrons of calcite deposited on well-crystallized dolomite. Locality unknown.

2. Fine crystals of calcite, slightly etched, a combination of prism with rhombohedron, deposited on a crystalline layer of dolomite. This, in turn, was deposited on large scalenohedrons of calcite. The dolomite of this specimen was also analyzed. (See dolomite No. III.) Ouray, Colorado.

3. Small scalenohedrons of calcite deposited on well-crystallized dolomite. Joplin, Missouri (?).

4. Small etched scalenohedrons on a crystalline deposit of dolomite. Guanajuato, Mexico.

5. A single crystal of calcite deposited on a mass of well-crystallized dolomite. Cave of the Winds, Niagara.

6. A large, water-clear crystal of calcite, associated with pink rhombohedral dolomite. Joplin, Mo.

The analyses are given in Table I.

Of the six analyses of calcite, all but one (No. 6) show a reasonably constant amount of magnesium carbonate. The average amount in the five analyses is 0·97 per cent and the greatest deviation from this value amounts to only 0·17 per cent. Coming as the specimens do, from a number of widely separated localities, and varying greatly in habit, it is certain that they were formed under varying conditions. The conclusion appears justified, therefore, that calcite is saturated by

* This Journal, vii, 187, 1899.

TABLE I.

Analyses of Calcite Deposited on Dolomite.

	1 Sp. gr. 2·713—2·722			2 Sp. gr. undet. Ouray, Colorado.		
	a	*b*	Average	*a*	*b*	Average
$MgCO_3$	1·08	0·98	1·03	0·79	0·80	0·80
$CaCO_3$	99·06	99·08	99·07	96·71	96·48	96·59
$MnCO_3$	0·12	0·10	0·11	2·92	2·94	2·93
	100·26	100·16	100·21	100·42	100·22	100·32

	3 Sp. gr. undet. Joplin, Mo. ?			4 Sp. gr. 2·741—2·769 Guanajuato, Mexico		
	a	*b*	Average	*a*	*b*	Average
$MgCO_3$	1·03	1·06	1·04	1·07	1·12	1·09
$CaCO_3$	99·26	99·21	99·23	93·05	93·24	93·15
$MnCO_3$	0·17	0·18	0·18	5·80	5·70	5·75
	100·46	100·45	100·45	99·92	100·06	99·99

	5 Sp. gr. undet. Cave of the Winds, Niagara	6 Sp. gr. undet. Joplin, Mo.		
		a	*b*	Average
$MgCO_3$	0·87	0·47	0·42	0·44
$CaCO_3$	99·38	99·65	99·65	99·65
$MnCO_3$	0·42	0·22	0·22	0·22
	100·67	100·34	100·29	100·31

approximately one per cent of magnesium carbonate at common temperatures of crystallization. As we pointed out before, a nearly constant value is to be expected where the amount of material in solid solution is small, unless, indeed, the temperature variation is great. We know of no reliable data at present to show whether this limit varies appreciably with extreme temperature conditions. An examination of some of the magnesian limestones would probably give information on this point. A number of cases have been reported in which calcites contained more magnesia than has been found by us, but there is no evidence that the material analyzed was homogeneous. Thus, Eisenhuth* has analyzed two calcites containing respectively 3·01 and 1·52 per cent of magnesium carbonate. Both of his specimens contained insoluble matter, showing the material was not quite homogeneous, and it seems fully as

*Zeitschr. Kryst., xxxv, 582, 1901.

probable that there may have been a small amount of admixed dolomite as that the calcite itself contained this unusual amount of magnesium carbonate. The magnesium content of our No. 6 is lower than any of the others. In this case, the calcite was probably unsaturated. The crystal was a water-clear specimen projecting two or three centimeters from a mass of dolomite crystals which served as its base. The association was not an intimate one and the solution depositing calcite had evidently not become saturated with magnesium carbonate from the dolomite. The analysis is not given to show the limiting value but to show that fairly intimate association of the minerals is necessary in order that the limiting value may be reached. It is perhaps worth mentioning here that iron in appreciable quantities was not found in any calcite examined. No other samples of calcite were analyzed.

Dolomite.

The specimens of dolomite deposited on calcite were the following:

I. A crystalline layer of dolomite deposited on massive calcite. Guanajuato, Mexico.

II. Small rhombohedral crystals of dolomite deposited as a crust on scalenohedrons of calcite. Guanajuato, Mexico.

III. An occurrence similar to that of No. II. On the dolomite, calcite was subsequently deposited (see calcite No. 2). Ouray, Colorado.

The analyses are given in Table II.

TABLE II.

Analyses of Dolomite deposited on Calcite.

	I			II		
	Sp. gr. 2·865—2·914 Guanajuato, Mexico			Sp. gr. 2·891—2·907 Guanajuato, Mexico		
	a	*b*	Average	*a*	*b*	Average
$MgCO_3$	33·52	33·48	33·50	31·50	31·45	31·48
$FeCO_3$	6·14	5·95	6·05	8·43	8·49	8·46
$CaCO_3$	60·68	60·61	60·64	60·67	60·76	60·71
	100·34	100·04	100·19	100·60	100·70	100·65

	III		
	Sp. gr. 2·887—2·860 Ouray, Colorado		
	a	*b*	Average
$MgCO_3$	30·57	30·85	30·71
$FeCO_3$	3·45	3·40	3·43
$MnCO_3$	3·41	3·07	3·24
$CaCO_3$	63·03	63·04	63·03
	100·46	100·36	100·41

The analyses show that all specimens contained more or less ferrous carbonate, and one, manganese carbonate also. We consider that these components replace magnesium carbonate. The ratios are as follows :

	I	II	III
$MgCO_3$	·397	·373	·364
$FeCO_3$	·052	·073	·030
$MnCO_3$	----	----	·028
$CaCO_3$	·606	·607	·630

The ratios $\frac{CaCO_3}{(Mg,Mn,Fe)CO_3}$ calculated from these results are :

I	II	III
1·349	1·361	1·492

These ratios show a somewhat surprising excess of calcium above the dolomite ratio, and the excess is variable. Since the material was homogeneous, but deposited directly on calcite, we see no reason why the ratios do not represent approximately limiting values for calcium carbonate in dolomite. From the fact that dolomite occurs so generally in the 1 : 1 ratio, Retgers* assumed that this ratio could not be much exceeded, but this appears not to be the case. The variable ratio is not unexpected and should be due in large part to the influence of temperature at the time of formation. These were all the specimens analyzed, in which dolomite was clearly the secondary mineral. One specimen was obtained in which there was primary formation of dolomite followed by the formation of a single large calcite crystal. (See calcite anal. No. 6.) About the base of the calcite, a small quantity of dolomite had subsequently formed. Both deposits were similar in appearance and could not be separated. A sample, chipped off near the base of the calcite crystal and containing some of each deposit, gave the following results on analysis :

Sp. gr. 2·834–2·868

Joplin, Mo.

	a	*b*	Average
$MgCO_3$	40·31	40·13	40·22
$FeCO_3$	1·91	1·93	1·92
$CaCO_3$	58·19	58·13	58·16
	100·41	100·19	100·30

The ratio $\frac{CaCO_3}{(MgFe)CO_3}$ calculated from these results is 1·176.

* Loc. cit., vi, 227, 1890.

The proportion of calcium in this case is much larger than is commonly found in a dolomite, but it cannot be regarded as a limiting ratio, as some of the primary dolomite was present.

Our results do not show whether the effect of increased temperature will be to increase or diminish the proportion of lime at the mixing limit. In this case, as in that of calcite, it is probable that the investigation of limestones containing magnesia would give some information.

In conclusion, we wish to call attention to the fact that the quantitative isomorphous relations between other mineral carbonates are quite unknown. To what extent, for instance, siderite or rhodochrosite can take up calcium carbonate has not been determined. It seems not unlikely that some of these problems, at least, may be settled by artificial preparations, and this method would have the very great advantage of working under known temperature conditions.

Chemical and Mineralogical Laboratories
of the Sheffield Scientific School of Yale University,
New Haven, Conn., Feb., 1914.

SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *Fused Magnesium Chloride as a Crystallizing Agent.*—K. A. Hofmann and K. Höschele have observed that magnesium chloride in the anhydrous, fused condition is an excellent solvent and means of crystallization for many inorganic substances. The salt melts at 708° C., a temperature easily obtained by means of a good Bunsen burner, to a very mobile liquid which dissolves many metallic oxides, and some of these crystallize very well upon cooling the solution. Other oxides, and particularly sulphates, react with the fused magnesium chloride and yield volatile chlorides, as for example the chlorides of beryllium, zinc, iron and tin. In other cases compounds of the spinel class are formed by the combination of oxides with magnesium oxide. The latter is formed by the action of the moisture of the flame or the oxygen of the air upon the magnesium chloride. This action leads also to the formation of large brilliant octahedral crystals of magnesium oxide (periclase) which often become mixed with other products. This decomposition of magnesium chloride leads to the corrosion of platinum, gold, silver and copper vessels in which the fusions are made. The platinum is deposited again in the form of beautiful hexagonal crystals, the gold forms iso-

metric crystals, the silver is deposited as crystalline chloride, while the copper gives red crystals of artificial cuprite, Cu_2O. Covered platinum vessels are only slightly attacked by the fusions, and porcelain crucibles resist the action for many hours. Among the compounds prepared were crystallized magnesioferrite, $MgFe_2O_4$ and products intermediate between this and magnetite, $FeFe_2O_4$, well crystallized magnesium orthoborate, $Mg_3B_2O_6$, and magnesium uranate, $Mg_3U_2O_9$. Cerium dioxide was crystallized by using the sulphate in the magnesium chloride fusion. The authors regard this as one of the most beautiful substances of inorganic chemistry, as it forms colorless cubic or octahedral crystals which are very hard, resembling diamond in brilliancy and luster, and having a refractive index above 1·9. By the use of a small proportion of praseodidymium sulphate mixed with the cerium sulphate, reddish yellow to deep red crystals were obtained. Zirconium dioxide also was obtained in the form of white tetragonal crystals. The rare earths, used as sulphates or oxides, gave well crystallized oxychlorides, for instance ErOCl was the erbium compound. The authors have studied the absorption spectra of a number of these products.—*Berichte*, xlvii, 238. H. L. W.

2. *Carbon Sulphide-Telluride and Carbon Sulphide-Selenide.*—Alfred Stock, P. Praetorius, and E. Willfroth have prepared the compounds CSTe and CSSe by passing an electric arc under cooled carbon disulphide between a cathode of tellurium or selenium and an anode of graphite. The tellurium compound is very unstable and difficult to purify. It is decomposed by light and exists only at low temperatures. It was purified by distilling in a high vacuum at −35° C. and condensing at −80° C. At low temperatures it is a yellowish-red solid which melts at −54° C. to a brilliant red liquid, and this becomes blood-red at room temperature, then turns black and soon decomposes completely. It has a garlic-like odor. The selenium compound is much more stable than the other. At room temperature it is a liquid of intense yellow color. Its melting point is −85° C. and the boiling point 84° C. It has an irritating garlic-like odor. It is decomposed by light and by long standing at room temperature. At higher temperatures it decomposes more rapidly, forming carbon disulphide, carbon and selenium. In the study of both the tellurium and selenium compounds careful search was made for the presence of the possible compounds CTe_2 and CSe_2, but no evidence of their formation could be found.—*Berichte*, xlvii, 131, 144. H. L. W.

3. *Double Bromides of Gold.*—A. Gutbier and J. Huber have prepared and described about eighty double salts of $AuBr_3$ with other bromides, most of which are bromides of organic bases derived from ammonia, but they include the potassium, rubidium and caesium salts, $KAuBr_4$, $RbAuBr_4$ and $CsAuBr_4$, the last two of which were described in this Journal by Wells and Wheeler in 1892. Examples of the organic base compounds analogous to the ammonium salts, NH_4AuBr_4, are the monomethyl ammonium

salt $(CH_3NH_2)AuBr_4$, the tetra-ethyl ammonium salt $(C_2H_5)_4N$-$AuBr_4$, etc. The authors have decided from their experience with a large number of salts that the double gold bromides of the organic bases are not well suited for the examination of such bases on account of their usual difficult crystallization and their frequent instability.—*Zeitschr. anorgan. Chem.*, lxxxvi, 353.

H. L. W.

4. *The Gravimetric Determination of Selenium.*—Julius Meyer has shown that the evaporation of nitric acid solutions of selenious acid leads to the loss of appreciable amounts of the substance, and that the loss may be serious when the dry residue is heated for a long time on the water bath. Although several of the best authorities recommend the removal of nitric acid in the course of analysis by repeated evaporation with strong hydrochloric acid, Meyer has found that this operation leads to very serious losses even in the presence of potassium or sodium chloride. For instance, nearly one-half of 0·14 g. of selenium was lost by evaporating its nitric acid solution to dryness twice with concentrated hydrochloric acid. The author recommends the employment of hydrazine hydrate for the precipitation of selenium, and he states that the interfering effect of nitric acid may be overcome by the addition of ammonia and some hydrochloric acid.—*Zeitschr. analyt. Chem.*, liii, 145. H. L. W.

5. *Active Nitrogen.*—E. Tiede and E. Domcke maintain that Strutt's phenomena attributed to active nitrogen, which are produced by passing electric sparks through nitrogen at low pressures, do not occur when pure nitrogen is employed, and that they are due to the presence of oxygen in the gas used. When they used pure nitrogen prepared by heating barium or sodium azide no luminescence occurred. By the use of hot metallic copper they were able to purify commercial nitrogen so that the after-glow did not occur, but they showed that the addition of oxygen to the gas brought about its appearance. The curious fact was brought out that metallic copper will remove the oxygen from its mixture with nitrogen at temperatures between 325° C. and 570° C., but that when the temperature is between 570° C. and 700° C. some oxygen remains in the gas, evidently on account of the dissociation of copper oxide at the low pressures (2 to 12^{mm}) employed.—*Berichte*, xlvii, 420. H. L. W.

6. *Rays of Positive Electricity and their Application to Chemical Analyses;* by Sir J. J. Thomson. Pp. vii, 132, 50 figures and 5 plates. London, 1913 (Longmans, Green and Co.).—This book will doubtless be received with enthusiasm by most physicists because it gives a consecutive account of the brilliant series of researches on positive rays carried out during the past seven years in the Cavendish Laboratory. Some idea of the scope of the work may be formed from the following list of headings of the sub-divisions of the text. (The material is not arranged in numbered chapters.) "Rays of Positive Electricity. Double Cathodes. Rectilinear Propagation of the Positive Rays. Elec-

trostatic Deflection of the Particle. Effect at Very Low Pressures. Discussion of the Photographs. Negatively Charged Particles. Atoms Carrying Two or More Positive Charges. Methods for Measuring the Number of the Positively Electrified Particles. Retrograde and Anode Rays. Anode Rays. Doppler Effect Shown by the Positive Rays. Spectra Produced by Bombardment with Positive Rays. Disintegration of Metals under the Action of Positive Rays. On the Use of the Positive Rays for Chemical Analysis. On the Nature of X_3 the Substance giving the '3' Line. Evolution of Helium and Neon." In his preface the author says;—"I have described at some length the application of Positive Rays to chemical analysis; one of the main reasons for writing this book was the hope that it might induce others, and especially chemists, to try this method of analysis." It will be very surprising if this hope is not vain, at least in so far as it relates to chemists, because practically no data are recorded which would enable a beginner in the subject either to order the necessary apparatus or to apply the general principles laid down, without spending a very large amount of time in letter writing or in performing preliminary experiments. The proof seems to have been read hurriedly since a number of typographical errors have been overlooked and since several of the figures lack the reference letters used in the text. The book will be chiefly useful to those who are already familiar with the original articles published in the Philosophical Magazine and elsewhere, and who desire to review the whole subject without undue labor.

H. S. U.

7. *Photo-Electricity;* by H. Stanley Allen. Pp. x, 221; 35 figures. London, 1913 (Longmans, Green and Co.).—"The present book is based on a course of advanced lectures delivered by the author at King's College, London, during the Lent Term of 1910; but the greater part has been entirely rewritten so as to incorporate the results of the large amount of research carried out in the three years since these lectures were given." The introductory chapter, which gives an outline of the whole field, is followed by chapters on the emission of electrons in a vacuum, on the velocity of the electrons, and on the photo-electric current in gases at various pressures respectively. After discussing photo-electric substances in the various physical states the author turns his attention to the influence on the photo-electric discharge produced by temperature, and by the character, intensity and plane of polarization of the exciting light. The remaining chapters deal with the theories of photo-electric action, photo-electric fatigue, fluorescence and phosphorescence, and photo-chemical actions and photography. The volume ends with both author and subject indices. The text is a valuable contribution to this branch of physics because in it are brought together, in English, for the first time, the experimental results and hypotheses which are widely scattered in the various scientific journals. Furthermore, the appearance of this book is especially timely since the most recent work

of Hallwachs, Fredenhagen and Küstner bids fair to simplify and perhaps revolutionize certain chapters of the subject, so that the volume will greatly facilitate the comparison and adjustment of the earlier and latest ideas and results. H. S. U.

8. *An Introduction to the Mathematical Theory of Attraction;* by FRANCIS A. TARLETON. Vol. II, pp. xi, 207. London, 1913 (Longmans, Green & Co.).—In the preface to the first volume, which was published about fourteen years ago, (see vol. viii, page 88, 1899) the author says: "... I hope, at some future time, to make this book more complete by the addition of chapters dealing with Spherical Harmonics, Conjugate Functions, and the Theory of Magnetism for bodies having finite dimensions." This hope is fulfilled by the present volume, which begins with chapter eight and ends with chapter twelve. The original plan has been departed from in two respects, namely, the subject of conjugate functions has been omitted and a chapter on Maxwell's theory of light has been added. The more recent developments of the electromagnetic theory of light are not touched upon. The treatment lays more stress on the mathematical than on the physical aspects of the topics discussed. The analysis would have been simplified and made more elegant and up-to-date if the author had used vector methods instead of scalar notation. The index is immediately preceded by a "Note on Thomson and Dirichlet's Theorem." H. S. U.

9. *The Chemistry of the Radio-elements. Part II. The Radio-elements and the Periodic Law;* by FREDERICK SODDY. Pp. v, 46. London, 1914 (Longmans, Green and Co.).—This little book deals with the following topics: The periodic table. Chemical and electro-chemical advances. The connection between the sequence of changes and the chemical properties of the products. The branching of the disintegration series. Nature of the end products. Atomic weight of lead. The origin of actinium. The spectra of isotopes. Neon and metaneon. Nature and properties of isotopes. The structure of atoms. Nature of the argon gases. The definitions of the new words "isotope" and "isotopic" may merit quotation. "... a group of two or more elements occupying the same place in the Periodic Table, and being in consequence chemically non-separable and identical, will be referred to as a group of isotopes, and, within the group, the separate members will be referred to as isotopic." "Thus ionium, thorium, and radio-thorium are isotopes, and mesothorium 1 is isotopic with radium." H. S. U.

10. *Modern Seismology;* by G. W. WALKER. Pp. xii, 88; 13 figures and 13 plates. London, 1913 (Longmans, Green and Co.). —The first five chapters of this book relate to seismometry and the remaining five to seismogeophysics. More specifically, the first 36 pages treat of the general dynamical theory of seismographs and the installation, standardization, sensitiveness, damping, mechanical and electromagnetic registration of the five chief types of seismographs in actual use. The rest of the text is

devoted to the theory of a solid isotropic earth, to the interpretation of seismograms, to the determination of epicenter and focus, and to statistical problems. The presentation of the subject is clear and logical, the illustrations are well selected and neatly reproduced, and the entire volume should be very useful, both as an introduction to this important field of investigation and as a practical guide to the use of seismographs. A pocket on the inside of the back cover of the book contains three specimen plates of seismograms recorded by Galitzin instruments at Eskdalemuir at the times of the Dardanelles and Zante earthquakes. H. S. U.

11. *Alternating Currents and Alternating Current Machinery;* by DUGALD C. JACKSON and JOHN PRICE JACKSON. Pp. ix, 968; 526 figures. New York, 1913 (The Macmillan Co.).—Since the appearance of the first edition in 1896 the subject has grown rapidly so that the present volume has been rewritten and greatly extended as compared with the earlier edition. (See this Journal, vol. ii, page 455, 1896.) Some of the improvements of the text may be briefly stated as follows: More attention is paid to the transient state in electric circuits than formerly. A considerable amount of related matter has been introduced in respect to vectors, complex quantities and Fourier's series. The treatment of power and power factor has been given great attention, and an entire chapter is now devoted to the hysteresis and eddy current losses which are developed in the iron cores of electrical machinery. The discussion of synchronous machines and of asynchronous motors and generators has been amplified and made more complete. Finally, the treatment of the self-inductance and mutual-inductance of line circuits and skin effect in conductors has been extended and supplemented by the consideration of electrostatic capacity of lines and the influences of distributed resistance, inductance, and capacity.

The manner of presentation is intended to serve a twofold purpose, namely, to fulfil the requirements of classes in engineering schools and to serve as a reference book for electrical engineers. Scattered throughout the volume may be found 208 problems for solution by the student, and also a fairly large number of footnotes referring to other standard texts and original journal articles. The book under consideration is apparently the best and most up-to-date on the subject in the English language. H. S. U.

12. *The mutual Repulsion of rigid Parallel Plates separated by a Film of Air;* by C. BARUS. (Communicated.)—By the application of displacement interferometry to the horizontal pendulum,* I find that two parallel rigid plates whose distance apart is of the order of 1^{mm} and less repel each other in air, with a force far in excess of their gravitational attraction. This force increases rapidly (certainly as fast as the inverse square) as the distance of the plates decreases and vice versa, but can be recognized beyond a millimeter of distance. For brass plates 20^{cm} in diameter and

* The full method will be shown later in this Journal.

1^{mm} apart, the repulsion in question is of the order of ·5 dyne and therefore equivalent to a pressure of ·0015 dynes/cm or roughly 10^{-9} atmospheres. It is in excess of any electric repulsion due to the absolute voltaic potential of the discs. The suspended plate reaches its position of equilibrium gradually, the motion progressing at a retarded rate through infinite time, in a way characteristic of the viscosity of the film of air between the plates.

I have estimated the intensity of the force both from the repulsions of a vertical plate suspended from the horizontal pendulum on opposite sides of a fixed parallel identical plate; also by charging pairs of plates to a given difference of potential for a given distance apart. So far as can be seen, the repulsion is caused by the condensation of air on the surface of the plates by molecular and not by gravitational force (which is too small). Hence, the method employed should enable the observer to find the density of the concentration in terms of the distance from the plate and the law of attraction of the plate in terms of distance, within the small distances in question. In other words, a method for the direct investigation of molecular force is here apparently given.

Brown University, Providence, R. I., Feb. 24.

II. Geology and Mineralogy.

1. *Third Annual Report of the Director of the Bureau of Mines*, Joseph A. Holmes, *for the fiscal year ended June 30, 1913.* Pp. vii, 118. Washington, March, 1914.—The Bureau of Mines was established by act of Congress in 1910, and began its work on July 1st of that year, taking over the investigations lying in its field which had been carried on previously by the U. S. Geological Survey. A new act of February 25, 1913, established a bureau of "Mining, Metallurgy, and Mineral Technology," widening the scope of the Bureau and enlarging its purposes and more clearly defining its work. This enlargement was the gratifying result of a general demand throughout the country; but it is to be regretted that as yet no direct provision has been made for carrying the larger plans into effect.

The record of work accomplished during the three years of the existence of the Bureau is a notable one and deserves fuller treatment than can be given here. The general subject of safety in mining, particularly with reference to investigating the causes and the means of prevention of coal-mine explosions, and the safe-guarding of the miners, was the one to which the energies of the Bureau were first directed, and in which most has been accomplished. Mine-rescue and first-aid work have also been pushed forward with vigor, and it is satisfactory to learn that the percentage of deaths per thousand employees due to accidents in the coal mines have been reduced from 4·88 in 1907 to 3·27 in

1912. In connection with this subject, extensive investigations have been carried on, both in the physical and chemical line, of explosives used in mining, also of the use of electricity and of safety lamps in coal mines.

Another important branch of the Bureau's work, prosecuted especially during its third year, and to be enlarged in the future, is the prevention of economic waste in mining in all its branches. The statement is made that a million dollars a day is not an unreasonable estimate for the waste now going on in the mineral resources of the country. In mining and handling coal alone, it is estimated that 250,000,000 tons per year represent the annual loss, of which a considerable part could be saved, were it practicable to carry through the thorough investigation of the subject which has been definitely planned. In the oil and gas fields of the country, the unnecessary waste is on a similar large scale aggregating some $50,000,000 per year, 80 per cent of which is believed to be easily preventable. During the current year a waste valued at some $10,000,000 in natural gas alone has been arrested, but much more could be accomplished in the same line. A sum of about $525,000 is given as an estimate of what is needed to carry forward some fourteen definitely specified lines of the Bureau's work; it is much to be hoped that the National and State governments may see the importance of granting the necessary support. During the year, 14 bulletins, 25 technical papers, and 3 miners' circulars have been published, in addition to other reports; a summary of these is given in the present volume. A folded map of the United States shows the location of coal fields, metalliferous ore deposits and rescue cars and stations. The increase in the distribution of the Bureau's publications from 110,500 in 1910–11 to 832,000 in 1912–13 gives an indication of the growth of the interest of the public in its work.

2. *Canada Department of Mines.*—Recent publications of the Department of Mines of Canada are as follows (see vol. xxxvi, p. 79):

(1) Geological Survey Branch, R. W. Brock, Director.

Memoirs.—No. 23. Geology of the Coast and Islands between the Strait of Georgia and Queen Charlotte Sound, B. C.; by J. Austen Bancroft. Pp. viii, 152; 17 pls., 5 figs., and a map.

No. 29–E. Oil and Gas Prospects of the Northwest Provinces of Canada; by Wyatt Malcolm. Pp. vi, 99; 9 pls., 2 figs. and map.

No. 33. The Geology of Gowganda Mining Division; by W. H. Collins. Pp. vii, 121; 4 pls., 5 figs., 1 map.

No. 37. Portions of Atlin District, British Columbia: with special reference to Lode Mining; by D. D. Cairnes. Pp. ix, 129; 32 pls., 5 figs. and 1 map.

Guide Books.—The following useful guide books have also been issued:

No. 1. Excursion in Eastern Quebec and the Maritime Provinces. Part I. Pp. 1–207. Part II. Pp. 211–407. Maps and illustrations.

No. 2. Excursions in the Eastern Townships of Quebec and the Eastern Part of Ontario. Pp. 142; maps and illustrations.

No. 3. Excursions in the Neighbourhood of Montreal and Ottawa. Pp. 162; maps and illustrations.

No. 4. Excursions in Southwestern Ontario. Pp. 142; maps and illustrations.

Mines Branch.—Eugene Haanel, Director.

Summary Report of the Mines Branch of the Department of Mines for the Calendar Year ending December 31, 1912. Pp. ix, 174; 16 pls., 1 figure, 3 maps.

Annual Report on the Mineral Production of Canada during the Calendar Year 1912. John McLeish, Chief of the Division of Mineral Resources and Statistics. Pp. 339. Also Preliminary Report by the same author for 1913. Pp. 21.—The value of the mineral production in Canada rose to $135,000,000 in 1912 and $144,000,000 in 1913; these figures are to be contrasted with about $17,000,000 in 1890 and $64,400,000 in 1900. The chief products in order of value for 1913 are: coal, silver, pig iron, gold, copper, cement; 46 p. c. of the whole production belongs to the metals and 54 to non-metallic products.

Economic Minerals and Mining Industry of Canada; by the Staff of the Mines Branch. Pp. 77; 19 pls. and map (also an edition in French).

The Nickel Industry with special reference to the Sudbury Region, Ontario; by A. P. Coleman. Pp. 186; 63 pls., 14 figs., 9 maps. Noticed on p. 121, Jan., 1914.

Austin Brook Iron-bearing District, New Brunswick; by E. Lindeman. Pp. 15; 3 pls., 5 figs., 3 maps.

Magnetite occurrences along the Central Ontario Railway ; by E. Lindeman. Pp. 23; 9 pls., maps 185–204 in separate cover.

Also (in French): Report on the Tungsten Minerals of Canada; by T. L. Walker. Pp. 56; 9 pls., 6 figs.

Report on the Chromic Iron Deposits in Eastern Quebec; by Fritz Cirkel; pp. 145, 11 pls., 15 figs.

3. *Report of Topographic and Geologic Survey Commission of Pennsylvania, 1910–1912.* Pp. 182; pls. i–xxi, figs. 23. Harrisburg, 1912.—Under a coöperative agreement between the Federal and State Surveys, topographic and geologic survey work in Pennsylvania has been in progress for several years. There have been issued 137 topographic sheets, covering 51·7 per cent of the state; 31 quadrangles have been surveyed geologically; and five bulletins dealing with oil, gas, paint, ores, and graphite have been issued. Included in the report for 1910–12 are the following papers: The York Valley Limestone by M. L. Jandorf, chiefly economic (pp. 50–129); Geological origin of the Freshwater fauna of Pennsylvania, by A. E. Ortmann (pp. 130–149); and a peridotite dike in Fayette and Greene Counties, by Lloyd B. Smith (pp. 150–155). The last mentioned paper gives additional details regarding this interesting intrusion, described in 1907 by Ross and Kemp. The article by Ortmann is a valuable

physiographic-biologic study of a problem of general scientific interest. The conclusion is reached that the interior basin was the center of origin of forms found both west and east of the Appalachians and that "the Atlantic side received its forms secondarily by migration from the interior basin." H. E. G.

4. *Graphite Deposits of Pennsylvania;* by BENJAMIN L. MILLER. Pp. 147; 17 pls. Topogr. Geol. Surv. Penn., Report No. 6. Harrisburg, 1912.—Following a discussion of the history, properties, origin, occurrence, distribution, and uses of graphite in general (pp. 3–66), Professor Miller describes in detail the scientific and commercial aspects of the individual mines in Chester, Berks, Lehigh, and Bucks Counties. H. E. G.

5. *Geological Survey of New Jersey*, HENRY B. KÜMMEL, State Geologist.—The New Jersey Survey, strengthened by the addition of M. W. Twitchell, geologist, continues to render efficient service to its state by publishing contributions of educational and economic value. Refinements of topographic surveys, soil mapping, ground water investigations, tests of road materials, and archeological research, and a special field study of the Eocene occupied the attention of the Survey staff during 1912. The report on the Pleistocene of southern New Jersey, by R. D. Salisbury, is in process of publication. Among the papers issued during the past year are: Bulletins 8 and 9, noticed on p. 78, vol. xxxvi; also Bulletin 10, The mechanical and chemical composition of the soils of the Sussex area, by A. W. Blair and Henry Jenning (110 pp.); Bulletin 11, The Mineral Industry of New Jersey for 1912, by M. W. TWITCHELL. (43 pp.) H. E. G.

6. *U. S. Geological Survey, Geologic Atlas of the United States, Niagara Folio, New York;* by E. M. KINDLE and FRANK B. TAYLOR. 1913. Pp. 28; 5 maps, 3 plates, bibl.—The Niagara Folio has been prepared with the care and fullness commensurate with the important place which this area occupies in the geologic history of North America. The geologic interpretation involves mainly stratigraphic and physiographic studies and the standing of the authors in their respective fields insures adequate presentation as well as scientific accuracy. The publication of this folio will relieve the geologist and layman alike from the necessity of examining the voluminous literature relating to Niagara which has accumulated during a century of study.

H. E. G.

7. *Union of South Africa, Mines Department. Annual Reports for 1912.* Part IV, Geological Survey. Pp. 188. Pls., maps, sections, 1913.—The Cape Geological Commission has become amalgamated with the Geological Survey of the Union of South Africa, thus providing a larger force engaged in attacking the problems presented by the southern portion of the Continent. The work of the geologists of the separate surveys,—Kynaston, Mellor, and Hall in the Transvaal; Humphrey in Natal; Rogers and DuToit in the Cape Province, has furnished solutions for many problems in stratigraphy, structure and economic geology;

and by means of reconnaissance has outlined the work remaining to be done. The Cape Commission, in particular, has maintained a high standard, deliberately concentrating its efforts "on the scientific elucidation of the geology of the Cape province without allowing itself to be drawn away into economic questions." With the Director's report for 1912 are published the following papers: The Geology of the Western Witwatersrand, by E. T. Mellor, pp. 29–66; The Geology of a Portion of the Marico and Rustenburg Districts, North of the Dwarsberg, by H. Kynaston, pp. 67–80; The Geology of the Country between Middelburg and Belfast, by A. L. Hall; The Geology of a Portion of Northern Natal between Vryheid and the Pongola River, by W. A. Humphrey, pp. 99–124; Report on a Portion of Namaqualand, by A. W. Rogers, pp. 125–152; The Geology of Pondoland, by A. L. duToit, pp. 153–180. H. E. G.

8. *Inter-State Conference on Artesian Water. Report of Proceedings.* Sydney, 1912. Pp. xvi, 68; 40 maps and plates.—An admirable method of attacking the problem of water supply for a large area is indicated by the organization of the Interstate Conference of Australia. Representatives from New South Wales, Queensland, West Australia, and Victoria took active part in the discussions which were grouped under the following heads: Definition of terms, Origin of artesian water, Outlets to the Great Australian artesian basin, Delimitation of the artesian basin, Hydrographic survey, Annual record of water drawn from artesian basins, Collection and Classification of Rocks obtained in boring, Uniform system of casing, Analyses of artesian waters, Decrease in flow of artesian bores, Utilization of artesian water, Corrosion of casing, Uniform legislation.

The statistics compiled and the reports prepared as a result of this conference, and published as Appendices A–Z_3, present in detail the present status of water development in Australia. Among the contributions of more than local value are the analyses of 450 well waters from New South Wales, by John C. H. Mingaye and others, and The Artesian Water Resources of Western Australia by A. Gibb Maitland, including analyses and many geologic sections. A majority of the wellbores listed are between 1000 and 2000 feet in depth; many are over 3000 feet deep, and 22 (5 in New South Wales, 2 in the Great Australian Basin and 15 in Queensland) exceed 4000 feet in depth. The maximum depth noted is 5,045.

The 40 maps, sections, and plates which constitute the second volume of the report furnish an atlas of value for geologists, geographers, and engineers. H. E. G.

9. *The Ocean: A General Account of the Science of the Sea;* by Sir John Murray. Pp. 256; pls. i–xii. New York, 1913 (Home University Library of Modern Knowledge, No. 76. Henry Holt & Company).—"The Ocean" should appeal to that large body of men of scientific interests who find little published material which is free from the limitations of exhaustive treatises

on the one hand, and of dogmatic textbook statements on the other. The extended experience of Sir John Murray, naturalist of the "Challenger" Expedition (1872–76), and of the "Michael Sars" Expedition (1910), commands interest in any publication which comes from his pen. While the book under review reveals the author's well-known scientific demand for accuracy and includes recent data and results of investigations, it is delightful reading for those who are laymen in oceanographic research. The scope of the book is indicated by the following chapter headings: Historical notes; methods and instruments of deep-sea research; the depth of the ocean; the waters of the ocean: salinity, gases; the waters of the ocean, temperature; the waters of the ocean: compressibility, pressure, color, viscosity, penetration of light, tides, waves, seiches; oceanic circulation; life in the ocean: plants; life in the ocean: animals; marine deposits; the geospheres. The oceanographic maps (Pls. II–VI and XI) of deeps, salinity, surface temperature, currents, density and deposits, and plates of deep sea organisms, constitute a valuable feature of the work. H. E. G.

10. *Descriptions of Land: A Text-book for Survey Students;* by R. W. Cautley. Pp. ix, 89. New York, 1913 (The Macmillan Company).—A land surveyor or geologist working in Canada will find Mr. Cautley's text of direct value. It is a common sense guide to a higher standard of accuracy in the description of public land. H. E. G.

11. *Interpretation of Anomalies of Gravity*, by Grove Karl Gilbert. Part C of Professional Paper 85, U. S. Geological Survey, pp. 29–37, 1913.—Hayford and Bowie in their work on gravity anomalies assumed in their computations that isostatic compensation was uniform and distributed everywhere to a uniform depth. Furthermore, that every topographic feature was compensated for by a corresponding variation in density. Having computed the value of gravity for each station on these assumptions, the differences between the observed and computed value gave the gravity anomaly. This they interpret as measuring the degree of imperfection of isostatic adjustment. Gilbert shows, however, that isostatic compensation could be perfect at the bottom of a zone of compensation and yet moderate vertical heterogeneities of density could give rise to anomalies as great as those actually observed. Thus the mere existence of anomalies does not prove departure from equilibrium. Variation in the depth of compensation could also give rise to anomalies. Still further, variations in density below the zone of compensation, the results of nucleal heterogeneity, would also give anomalies at the surface. Thus the latter cannot be used as measures of departures from isostatic adjustment until all these other factors are evaluated. Gilbert has thus opened up a new aspect of the discussion of the problem of equilibrium in the earth's crust. J. B.

12. *The Mud Lumps at the Mouths of the Mississippi*, by Eugene Wesley Shaw. Pp. 10–27; figs. 6, pls. iii, 1913. Part B of

Professional Paper 85. Contributions to General Geology, U. S. Geological Survey.—This paper records many facts in regard to the mud lumps, those temporary islands of mud which swell up from the bottom of the mouths of the Mississippi. It is shown in this paper that they are especially common near the mouths of the passes, where the front of the delta is relatively steep. They are found to be thick masses of clay, ascribed by Shaw to the squeezing out of clay layers farther inland owing to the greater pressure above in that region. From the geologic standpoint they are therefore noteworthy in showing under special conditions the capacity of clay sediments for lateral flow. J. B.

13. *La Face de la Terre* (*Das Antlitz der Erde*), par Ed. Suess; traduit avec l'autorisation de l'auteur et annoté sous la direction de Emmanuel de Margerie. Vol. III, Part III. Pp. xi, 957 to 1350, with one colored map, 2 plates, and 92 figures. Paris, 1913 (Librairie Armand Colin).—Eighty of the figures have been drawn especially for this French edition and constitute a most valuable addition to the volume. In the original work, the absence of good maps either left the reader with vague mental pictures of the regions described or required him to make use of a good geological library to supplement the text. The illustrations of the present volume, furthermore, are up to date, and excellently drawn. This comprehensive work thus is kept in the front rank of manuals of geology. The present volume treats of the structure of part of Africa, of the island chains off the coast of Asia, the Polynesian chains, and the American Cordillera. J. B.

14. *Water and Volanic Activity*, by Arthur L. Day and E. S. Shepherd. Bulletin of Geological Society of America, vol. xxiv, pp. 573–606, pls. 17–27, 1913.—In the past few years the problem of the nature of volcanic emanations has attracted much attention. Brun especially has argued sweepingly that, contrary to older views, water was practically absent and that the clouds issuing from the volcano consisted chiefly of chlorine and sulphur gases. The numerous subsidiary problems affected by this conclusion makes its verification or refutation of high importance. The present paper gives the evidence from Kilauea. A preliminary discussion of the arguments of Brun suggests that they are really not conclusive, but the final test was made by collecting gases issuing from the molten lava. Water instead of being absent was so abundant that it condensed in quantity in the collecting apparatus. Next in importance came CO_2 and N_2. Occurring in lesser proportion were found CO, H_2, and SO_2. J. B.

15. *Zeitschrift für Vulkanologie.* Herausgeber Immanuel Friedlaender, Naples. Band I, Heft 1, January, 1914.—This new journal, as its name implies, is planned as a medium for the publication of the literature of vulcanology. In this issue are original articles by Brun, Ponte, Perret, and Friedlaender. It should aid in the progress of vulcanology by stimulating study and centralizing the literature into a recognized special publication. J. B.

16. *Igneous Rocks and their Origin;* by R. A. Daly. Pp. 563, 8°; 205 figs. New York, 1914 (McGraw Hill Book Co.).—This work contains in somewhat changed and revised form the matter published by the author in previous years on various phases of petrology and igneous geology, such as the mechanics of igneous intrusion, the secondary origin of certain granites, classification of igneous intrusive bodies, origin of the alkaline rocks, average composition of rock types, origin of augite andesites, differentiation by gravitative adjustment, abyssal igneous injection, etc., together with the theoretical portion of the report on the Geology of the North American Cordillera at the Forty-Ninth Parallel. To this material, which contains the views of Professor Daly on various problems which igneous rocks present, and with which petrologists are familiar, much new matter has been added and the whole worked over to present in consistent and systematic manner a treatise upon the origin, emplacement, classification, and other varied relations of igneous rocks. It would be impossible in the limits which necessity imposes on this notice to present an adequate review of the work, but an idea of the mode of treatment of the subject may be gained by a statement of the chapter headings and the matter included in them. The author begins with a brief discussion of classification and the reasons for adopting the system of Rosenbusch, according to which the rocks are grouped into genetic clans. Then follows a study of the general distribution and relative quantities of the igneous rock species, and as a general result the writer finds that quantitatively the rocks belong chiefly in two clans, the granite and gabbro; the first among the visible rocks is mainly intrusive, the latter essentially extrusive (basalt). The diorite clan is also essentially extrusive (andesite), while the visible alkaline rocks (including the syenite and monzonite clans) have a volume less than one per cent of that of the subalkaline ones. These facts are considered to be of fundamental importance. After a brief discussion showing that qualitatively all the important clans are found in the different grand divisions of geologic time, attention is called to the persistence of the gabbro type, a prominent fact. Then follows a classification of intrusive bodies: first those produced by simple injection, such as laccoliths, and then those formed by replacement, like batholiths, followed by a chapter on extrusive masses, one type of which, it is suggested, may be the exposed portions of batholiths.

Part two of the book outlines a general theory for igneous rocks, beginning with a discussion of the composition of the earth in which an upper outer granitic shell resting on a lower basaltic one is assumed. Then follow chapters sketching the processes of abyssal injection of the lower basalt into the granitic shell. The method of intrusion by magmatic stoping is fully treated, which process involves the assimilation of the engulfed material and leads to the belief of the secondary origin of much rock-magma. The theoretical side of magmatic assimi-

lation in its varied phases is then treated, and this leads to the subject of differentiation. Magmas formed by assimilation (syntectics) may be split or differentiate and thus give rise to various types of igneous rocks. The process as it occurs in masses of various modes of occurrence is described, and is followed by a discussion of the theory of volcanic action in the central vents. The next chapter summarizes the author's general theory as to the origin of igneous rocks which is called the "eclectic" one, since it includes the ideas of many other petrologists. In a general way it is somewhat similar to the one propounded by Loewinson-Lessing, but differs in some important respects. The author then states a provisional genetic classification of magmas derived from considerations previously stated.

The last part of the work is devoted to a discussion of the different rock clans, of their relations, occurrences, and genetic derivation, and the work closes with several appendices giving the data upon which a number of conclusions have been reached. The work is clearly written and amply illustrated, and shows the evidence of a great amount of work in the examination of the literature and collating of material, and in field studies. Whether he may agree with all of the views here set forth by Professor Daly, or not, it is a work which should be read by every petrologist, as his interest in this subject cannot fail to be stimulated by the broad treatment of the subject matter and the enthusiasm for his ideas which is everywhere evinced by the author. L. V. P.

17. *Bergalite.*—A new variety of the basaltic rocks carrying melilite, from the Kaiserstuhl in Baden. This group of much dissected volcanoes consists of various alkalic types of magmas in flows, dikes, etc. The present rock occurs in a few small dikes, and when unaltered has a black somewhat pitchy appearance. In thin section it is seen to consist of phenocrysts of haüynite, apatite, perofskite, melilite, and magnetite, in a groundmass of melilite, haüynite, nephelite, biotite, perofskite, magnetite, and brown glass. Carbonates and zeolites are present from alteration. The melilites afford excellent material for the study of this mineral, especially the peg-structure, and the author concludes that this is not due to inclusions of glass, or other substances, but is a process of alteration into another mineral, to which the name of DEECKËITE is given. It was found that the peg substance was insoluble in strong hydrochloric acid which permitted sufficient material for an analysis to be obtained on dissolving the other constituents. From the analysis the formula $(HKNa)_2(MgCa)(AlFe)_2(Si_2O_5)_5 + 9H_2O$ was derived, which suggests that it is a zeolite near ptilolite and mordenite in composition.

The analysis of the rock shows it to be of a very basic nature, as follows:

SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O	CO_2	Rest
33·03	13·02	4·73	5·60	3·97	12·72	5·79	3·04	6·00	8·42	4·20 = 100·52

The rest includes TiO_2 1·35; MnO ·40; P_2O_5 ·58; SO_3 ·99; Cl 88. The rock is evidently closely related to alnöite, but differs in the lack of pyroxene and olivine.—*J. Soellner, Mitt. d. G. Bad. Geol. Landanst.*, vii, p. 415, 1913. L. V. P.

18. *Brief notices of some recently described Minerals.*—Maucherite is a nickel arsenide from Eisleben, Thuringia, Germany; it was described (1913) by F. Grünling and named after the discoverer, W. Maucher. Associated minerals are niccolite, chloanthite, bismuth, manganite, calcite, barite, etc. It occurs in masses having a compact or indistinct fibrous structure, and reddish silver-white color; also in rectangular tabular crystals. Hardness 5; specific gravity 7·83. An analysis by Prandtl gave: As 43·67, S 0·17, Ni 52·71, Co 2·15, Pb 0·20, Fe 0·40, gangue 0·40 = 99·70. This yields the formula $(Ni,Co)_3As_2$.—*Centralblatt Min.*, p. 225, 1913. A later investigation by A. Rosati has proved that the crystals are tetragonal and that the substance is identical in composition with the artificial furnace product called "nickelspeise" (placodin of Breithaupt).—*Zs. Kryst.*, liii, 389, 1914.

Hodgkinsonite is a new zinc-manganese silicate from Franklin Furnace, N. J., described by C. Palache and W. T. Schaller. It occurs in seams in a granular mixture of willemite and franklinite. Crystals are rare; these are monoclinic in form with perfect basal cleavage. The hardness is about 5; specific gravity 3·91; color from bright pink to pale reddish brown. An analysis (Schaller) gave:

SiO_2	MnO	ZnO	CaO	MgO	H_2O (above 110°)
19·86	20·68	52·93	0·93	0·04	5·77 = 100·21

The formula deduced is $Mn(ZnOH)_2SiO_4$.—*Journal Wash. Acad. Sci.*, iii, 474, 1913.

Yukonite is a new hydrous iron-calcium arsenate from Tagish Lake, Yukon, Canada; it is described by J. B. Tyrrell and R. P. D. Graham. It occurs in black or brownish black irregular concretionary masses in a quartz vein with galena and other sulphides. Structure amorphous; brittle with conchoidal fracture; hardness 2–3; specific gravity 2·65 becoming 2·86 after being long immersed. The mineral flies to pieces in water with a crackling sound and the disengagement of gas (chiefly CO_2). Two analyses (Graham) gave:

As_2O_5	Fe_2O_3	CaO	H_2O
34·06	35·72	10·00	20·28
33·83	36·81	10·14	20·28

The calculated formula is $2Ca_3As_2O_8.3Fe_2As_2O_8.5Fe_2(OH)_6.23H_2O$. It is somewhat related to arseniosiderite and mazapilite. —*Trans. Roy. Soc. Canada*, vii, section iv, 1913.

Epidesmine, described by Rosický and Thugutt, is a new zeolite occurring in minute colorless to pale yellow crystals from

Schwarzenberg in the Erzgebirge. An analysis (sp. grav. = 2·152) gave (freed from impurities):

SiO_2	Al_2O_3	CaO	MgO	K_2O	Na_2O	H_2O
55·92	16·00	7·58	0·06	0·67	0·88	18·69 = 99·80

—*Centralblatt Min.*, 1913, p. 422.

Kobaltnickelpyrite is a member of the pyrite group having the formula $(Co,Fe,Ni)S_2$. It is described by M. Henglein from the well-known locality at Müsen. It shows the pyritohedral form (320) with the cube and octahedron. It has a steel-gray color; hardness 5·55; specific gravity 4·72. An analysis gave: S 53·70, Fe 21·15, Ni 17·50, Co [6·61], insol. 1·04 = 100.—*Centralblatt Min.*, 1914, 129.

A supposed new vanadate from the copper mines near Ozieri, Sassari, Italy, is described by D. Lovisato. It occurs in minute black crystals resembling descloizite and according to an analysis by S. Manis contains :

V_2O_5	P_2O_5	PbO	ZnO	CuO	Fe_2O_3	MnO	H_2O
19·87	0·18	53·76	2·45	13·13	6·54	0·05	3·45 = 99·43

No name is suggested and the material evidently merits further investigation.—*R. Accad. Linc.*, xix, 2, p. 326 in Zs. Kr., lii, 311.

III. Miscellaneous Scientific Intelligence.

1. *Carnegie Institution of Washington*, Robert S. Woodward, President. *Year Book No. 12, 1913.* Pp. xvi, 336, with 13 plates. Washington, 1914.—The magnitude of the work of the Carnegie Institution is well shown by the fact that its total invested funds now amount to very nearly $23,000,000, to which must be added real estate, equipments, and publications of $2,000,000, with current assets of $624,000 or about $25,500,000 in all. The receipts for the year ending October 31st amounted to $1,500,000, of which $1,150,000 represents the income proper. The expenditure for the same period upon the ten large departments, to the support of which the Institution is committed, amounted to $700,000, while minor and special projects and research assistants received $110,000 ; in addition, $53,000 was paid out for publications, $43,550 for administration, and the balance of the total of $1,572,000 went into investments and on account of the Administration Building.

In the review of the work of the year, Dr. Woodward calls attention with satisfaction to the increased recognition which the work of the Institution as a whole has received, and the greater interest manifested throughout the world in the details of its organization and equipment. It is noted that a department of Human Embryology, under the direction of Professor Franklin P. Mall, has been planned and has already began active research. In the department of Experimental Evolution, two new buildings

have been added, one a heating and lighting plant, the other an additional laboratory. An office and laboratory building is also nearing completion for the department of Terrestrial Magnetism; this is situated near Chevy Chase, and in addition to other uses will give opportunity for experimental researches in terrestrial magnetism. The non-magnetic ship Carnegie has now nearly completed a circumnavigation voyage of three and a half years duration and aggregating about 92,000 miles. A fire-proof office building has also been constructed at Pasadena for the staff of the Solar Observatory. Dr. Woodward speaks feelingly and in detail of the invaluable services rendered to the Institution by the late Dr. John S. Billings.

The President gives further a summary of the work accomplished by each of the separate departments. This is supplemented by detailed reports from the directors of the departments and the recipients of grants for special investigations. These reports fill the greatest part of the volume (pp. 55–322) and contain much interesting information as to the work done, for example, in botany at Tucson, Arizona; in experimental evolution at Cold Spring Harbor, L. I.; in marine biology at Tortugas, Florida; in the Geophysical Laboratory at Washington; the Mt. Wilson Solar Observatory near Pasadena, etc. The publications of the year include 29 volumes, with an aggregate of 6,600 octavo and 2,750 quarto pages, and 30 additional volumes are now in the press.

The following publications have recently been issued (see vol. xxxvi, p. 575):

No. 163. Guide to materials for the History of the United States in the principal Archives of Mexico: by Herbert E. Bolton. Pp. xv, 553. (Papers of the Department of Historical Research, J. Franklin James, Editor.)

No. 172. Guide to the materials for United States History in Canadian Archives; by David W. Parker. Pp 339. (Dep't of Hist. Research as above.)

No. 184. The Subanu. Studies of a Sub-Visayan Mountain Folk of Mindanao. Part I. Ethnographical and Geographical Sketch of Land and People; by Lieut.-Col. John Park Finley. Part II. Discussion of the Linguistic Material; by William Churchill. Part III. Vocabularies. Pp. v, 236; 2 maps. (Dep't Hist. Research, as above.)

No. 187. Muscular Work. A Metabolic Study with special reference to the Efficiency of the Human Body as a Machine; by Francis G. Benedict and Edward P. Cathcart. Pp. vii, 176; 10 figures.

No. 188. Heredity of Skin Color in Negro-White Crosses; by Charles B. Davenport. With appendix, being abridgement of field notes, chiefly of Florence H. Danielson, Field Worker, Eugenics Record office. Pp. 106; 4 plates. (Paper No. 20 of the Station for Experimental Evolution at Cold Spring Harbor, N. Y.)

No. 195. Piebald Rats and Selection. An Experimental Test of the Effectiveness of Selection and of the Theory of Gametic Purity in Mendelian Crosses; by W. E. CASTLE and JOHN C. PHILLIPS. Pp. 54; 3 plates.

2. *Annual Report of the Superintendent of the United States Coast and Geodetic Survey*, O. H. TITTMANN, to the Secretary of Commerce for the year ending June 30, 1913. Pp. 102; one chart and 15 maps.—This Annual Report gives an account of the progress made by the Survey in the different lines of observation along the coast and in the interior of the United States and of its various dependencies. The results are clearly exhibited graphically by a series of charts indicating, for example, the progress in triangulation, topography, hydrography; also showing the principal astronomic stations, those for telegraphic longitude and magnetic observations, the leveling routes, etc.

The Survey has issued a large number of separate publications, including the following quarto volumes: Results of magnetic observations by D. L. Hazard, at Vieques, Porto Rico, at Sitka, Alaska, at Tucson, Arizona, at Honolulu, H. T.; Effect of topography and isostatic compensation upon the intensity of gravity, by W. Bowie (noticed in vol. xxxv, p. 197); Determination of time, longitude, latitude and azimuth, 5th edition, by W. Bowie; Triangulation along the west coast of Florida, by C. H. Swick.

3. *Newcomb–Englemanns Populäre Astronomie.* Fifth edition; edited by Professor P. KEMPF, Director of the Astrophysical Observatory of Potsdam, with the collaboration of Professors EBERHARD, LUDENDORFF and SWARTZSCHILD. Pp. xii, 835, 4to, with 228 illustrations and 27 tables. Leipzig and Berlin, 1913 (Wilhelm Englemann).—Newcomb's Popular Astronomy, first published in German translation by Englemann in 1881, has passed through successive editions as the progress of the science has made necessary its revision and enlargement until it has now reached the fifth and has grown in the process to a quarto of 835 pages with an index of 25 pages.

The ground plan of Newcomb, marked by the breadth, coherence and lucidity of the master mind, has been preserved intact and the details supplied with the thoroughness and minuteness of German scholarship have found room in it without overloading or confusion. The result is almost an encyclopædia of Astronomy. Each edition has been in charge of a recognized authority. After the first it was Vogel until his death in 1907, and he is succeeded by Kempf, director of the Astrophysical Observatory at Potsdam.

A valuable feature is a chapter of biographical sketches in 58 pages, of 185 astronomers from Thales and Pythagoras to Poincaré and Keeler. By it some men will obtain an immortality well deserved but which otherwise they might have missed. For example, it is well that posterity should know that Charlois, who died in 1910, spent 16 years in the observatory of Perrotin at Nizza and discovered over 100 minor planets—a worthy example of the same kind of usefulness as that of Schwab, the astro-

nomical apothecary of Dessau, whose "imperturbable telescope" drew from the sun the data for the sun spot theory. W. B.

4. *Milton's Astronomy. The Astronomy of Paradise Lost;* by THOMAS N. ORCHARD, F.R.S. Pp. viii, 288; 13 illustrations. London and New York (Longmans, Green & Co.).—The number of those who love intelligently both the science of astronomy and the poetry of Milton is not very large but to them this volume will be a source of both pleasure and information, and outside this select number it will do good in reviving an interest in the most sublime conception of the human imagination couched in the noblest forms of human expression.

Not the least remarkable aspect of Newton's genius was his scientific knowledge and not the least noticeable feature of it was his interest in astronomy.

Born in the year of the discovery of the principle of the telescope, he lived in the transition period when the conflict between the Ptolemaic and Copernican theories was at its bitterest stage and was fully conversant of its merits. His vast erudition supplied him with all the lore of the older theory, which he frequently used for poetic effect, and perhaps accepted at the time of writing his early poems.

But at the age of 30, during his tour of France and Italy, he spent four months in Florence and visited, we do not know how often, the aged Galileo, then blind and the object of the hatred and malice of the orthodox in science and of the hierarchy of the church. Milton's acute and liberal mind did not fail to grasp the import of what he saw with his own eyes through the "Tuscan artist's optic glass," and doubtless this is the cause of the profound impression that astronomy made upon his imagination. No topic of thought could be more congenial to that noble and exalted mind than the subject matter of this noblest and loftiest of sciences; and when 25 years later, himself blind and weary with battles for freedom of thought in England, he withdrew from the world and turned the eyes of his spirit upon the glories of Paradise, he enriched his portrayal with a glittering wealth of astronomical figures and allusions such as is to be found in no other of the masterpieces of literature. W. B.

5. *Trigonometry (Plane and Spherical, with numerous Tables);* by A. M. KENYON, Purdue University, and LOUIS INGOLD, University of Missouri. Edited by E. R. HEDRICK. Pp. 134. New York, 1913 (The Macmillan Co.).—The use of graphic methods in trigonometry is the only new feature which we find in any of the multitude of text-books in this subject which issue from the press perennially, furnishing perhaps a justification for publication in the books where it is used. Of the graphic method in trigonometry, however, it may be said: first, that the number of text-books presenting it is already so considerable that this excuse will soon be no longer valid, and, second, that these methods to be used comfortably are best studied first in connection with algebra.

They will be a much greater help in trigonometry if they have

preceded it than if facility has to be acquired while the attention is fixed on another new and quite different kind of manipulation.

The graphic method is freely used in this book. Though it contains a minimum of purely theoretical matter, it is more scholarly than most, and harder, therefore, for the average student.

W. B.

6. *Who's Who in Science, International, 1914;* edited by H. H. Stephenson. Pp. xx, 662. New York (The Macmillan Company).—The third issue of this most useful work shows a natural growth over its predecessor, numbering one hundred additional pages. Although anything approaching a complete list of the world's scientists would be hopelessly long, this classified index containing 9,000 entries is large enough to include those about whom it is most important to gain information. It may be noted that while the book is published in English and printed in Great Britain, the British element constitutes less than a quarter of the whole. In general, the lines laid down in the volume for 1913 are followed in the one now in hand. The opening pages contain an obituary for 1913, and following this a list of the universities of the world (pp. 1–52) and the scientific societies (pp. 53–117). The biographies cover five hundred pages and a classified index (pp. 622–662) shows at once what names are included from the different countries in each department.

7. *Franklin Institute award of the Elliott Cresson Medal.*—The Franklin Institute of Philadelphia has awarded the Elliott Cresson gold medal to Professor Wolfgang Gaede for his molecular air pump, in consideration of the very great value of this invention for the quick production of vacua beyond those hitherto obtainable. This pump depends for its action on the dragging of a gas by a rapidly moving surface. It consists essentially of a cylinder in which revolves a rotor. The peripheries of the cylinder and rotor are so formed that annular projections in the former very nearly fit into annular recesses in the latter. The rotor is revolved at from 8000 to 12000 revolutions per minute, and drags the gases to be exhausted with it past the stationary surface of the cylinder. The pump produces a vacuum of $\cdot 000001^{mm}$ in 4 minutes.

8. *The Cambridge Manuals of Science and Literature.* New York, 1913 (G. P. Putnam's Sons).—The following little books in the series (12mo) have been received :

The Wanderings of Animals ; by Hans Gadow. Pp. viii, 150 ; 17 maps.

The Theory of Money ; by D. A. Barker. Pp. vii, 141.

Copartnership in Industry ; by C. R. Fay. Pp. 146.

9. *Tables and other Data for Engineers and Business Men ;* compiled by Charles E. Ferris. Eighteenth edition. Pp. 244. Knoxville, Tenn. (University Press. Price 50 cents).—This new edition of the Manual for Engineers (see vol. xxviii, p. 566) has been extensively revised. In addition to the engineering tables, attention is given to instructions to be followed in case of electric shock, shop injuries, antidotes for poison, etc., information especially valuable to the active engineer.

Obituary.

Sir John Murray, the eminent Scotch naturalist and oceanographer, died suddenly as the result of an automobile accident on February 16 at the age of seventy-three years. Born at Coburg, Ontario, he removed to Scotland when still a youth and completed his education at the University of Edinburgh. When only thirty-one he was appointed naturalist to the "Challenger" expedition and took part in the cruises from 1872 to 1876, later serving as editor of the Challenger Reports (1880–1885). Other important investigations in oceanography occupied him in later years, the last of these, the Michael Sars expedition, in 1910 when nearly seventy years old. He was the author of many important memoirs and volumes: one of these entitled "The Ocean" (1913) is noticed on an earlier page of this number (p. 355).

Dr. Edward Singleton Holden, the astronomer and librarian of the United States Military Academy, died on February 16 at his home in West Point, N. Y., in his sixty-eighth year. In 1872 he was appointed astronomer in the U. S. Naval Observatory; from 1881–1886 he was professor of astronomy at the University of Wisconsin and director of the Washburn Observatory; from 1885–1888 president of the University of California and director of the Lick Observatory till 1898, when he became librarian at West Point. His contributions to astronomy were numerous and important.

William Whitman Bailey, professor emeritus of botany at Brown University, died on February 20 at the age of seventy-one years. He served as botanist to the U. S. Geological Survey of the Fortieth Parallel in 1867 and 1868 and was made professor at Brown in 1881, retiring from active service in 1906. He made numerous contributions to scientific journals and wrote a number of books: "Botanical Collector's Handbook" (1881), "Among Rhode Island Wild Flowers" (1885), "New England Wild Flowers" (1897) and others.

Dr. Giuseppi Mercalli, director of the Observatory on Mt. Vesuvius and professor of vulcanology and seismology at the University of Naples, died suddenly, as the result of an accident, on March 19 at the age of sixty-four years.

Dr. Albert Günther, the eminent German zoologist, died on February 1 in his eighty-fourth year.

Dr. H. B. Woodward, formerly assistant director of the British Geological Survey, died on February 6 at the age of sixty-five years.

Col. Alexander Ross Clarke, the English geodetist, died on February 11 at the age of eighty-five years.

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CONTENTS.

Page

ART. XXII.—The Rodadero (Cuzco, Peru),—A Fault Plane of Unusual Aspect; by H. E. GREGORY 289

XXIII.—Occurrence and Genesis of a Persistent Parting in a Coal Bed of the Lance Formation; by G. S. ROGERS. 299

XXIV.—About Climatical Variations; by H. ARCTOWSKI .. 305

XXV.—Late Paleozoic Glaciation in the Boston Basin, Massachusetts; by F. H. LAHEE 316

XXVI.—Note on the Use of the Wilson Tilted Electroscope; by H. W. FARWELL 319

XXVII.—Mammut Americanum in Connecticut; by C. SCHUCHERT. With a note on the Farmington specimen by R. S. LULL 321

XXVIII.—Hydrolysis of Esters of Substituted Aliphatic Acids; by E. W. DEAN 331

XXIX.—Solid Solution in Minerals. V. The Isomorphism between Calcite and Dolomite; by H. W. FOOTE and W. M. BRADLEY 339

SCIENTIFIC INTELLIGENCE.

Chemistry and Physics—Fused Magnesium Chloride as a Crystallizing Agent, K. A. HOFMANN and K. HÖSCHELE, 345.—Carbon Sulphide-Telluride and Carbon Sulphide-Selenide, A. STOCK, P. PRAETORIUS, and E. WILLFROTH: Double Bromides of Gold, A. GUTBIER and J. HUBER, 346.—Gravimetric Determination of Selenium, J. MEYER: Active Nitrogen, E. TIEDE and E. DOMCKE: Rays of Positive Electricity and their Application to Chemical Analyses, J. J. THOMSON, 347.—Photo-Electricity, H. S. ALLEN, 348.—Introduction to the Mathematical Theory of Attraction, F. A. TARLETON: Chemistry of the Radio-elements, Part II, F. SODDY: Modern Seismology, 349.—Alternating Currents and Alternating Current Machinery: Mutual Repulsion of rigid Parallel Plates separated by a Film of Air, C. BARUS, 350.

Geology and Mineralogy—Third Annual Report of the Director of the Bureau of Mines, 351.—Canada Department of Mines, 352.—Report of Topographic and Geologic Survey Commission of Pennsylvania, 1910–1912, 353.—Graphite Deposits of Pennsylvania, B. L. MILLER: Geological Survey of New Jersey: Geologic Atlas of the United States, Niagara Folio, New York, E. M. KINDLE and F. B. TAYLOR: Union of South Africa, Mines Department, Annual Reports for 1912, 354.—Inter-State Conference on Artesian Water: The Ocean: General Account of the Science of the Sea, J. MURRAY.—Descriptions of Land, R. W. CAUTLEY: Interpretation of Anomalies of Gravity, G. K. GILBERT: Mud Lumps at the Mouths of the Mississippi, 356.—La Face de la Terre, E. SUESS: Water and Volcanic Activity: Zeitschrift für Vulkanologie, 357.—Igneous Rocks and their Origin, R. A. DALY, 358.—Bergalite, 359.—Notices of recently described Minerals, 360.

Miscellaneous Scientific Intelligence—Carnegie Institution of Washington, 361.—Annual Report of the Superintendent of the United States Coast and Geodetic Survey: Newcomb-Englemanns Populäre Astronomie, 363.—Milton's Astronomy, The Astronomy of Paradise Lost, T. N. ORCHARD: Trigonometry, A. M. KENYON and L. INGOLD, 364.—Who's Who in Science, International, 1914: Franklin Institute award of the Elliott Cresson Medal: The Cambridge Manuals of Science and Literature: Tables and other Data for Engineers and Business Men, C. E. FERRIS, 365.

Obituary—J. MURRAY: E. S. HOLDEN: W. W. BAILEY: G. MERCALLI: A. GÜNTHER: H. B. WOODWARD: A. R. CLARKE, 366.

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FOURTH SERIES

VOL. XXXVII—[WHOLE NUMBER, CLXXXVII].

No. 221—MAY, 1914.

WITH PLATE IX.

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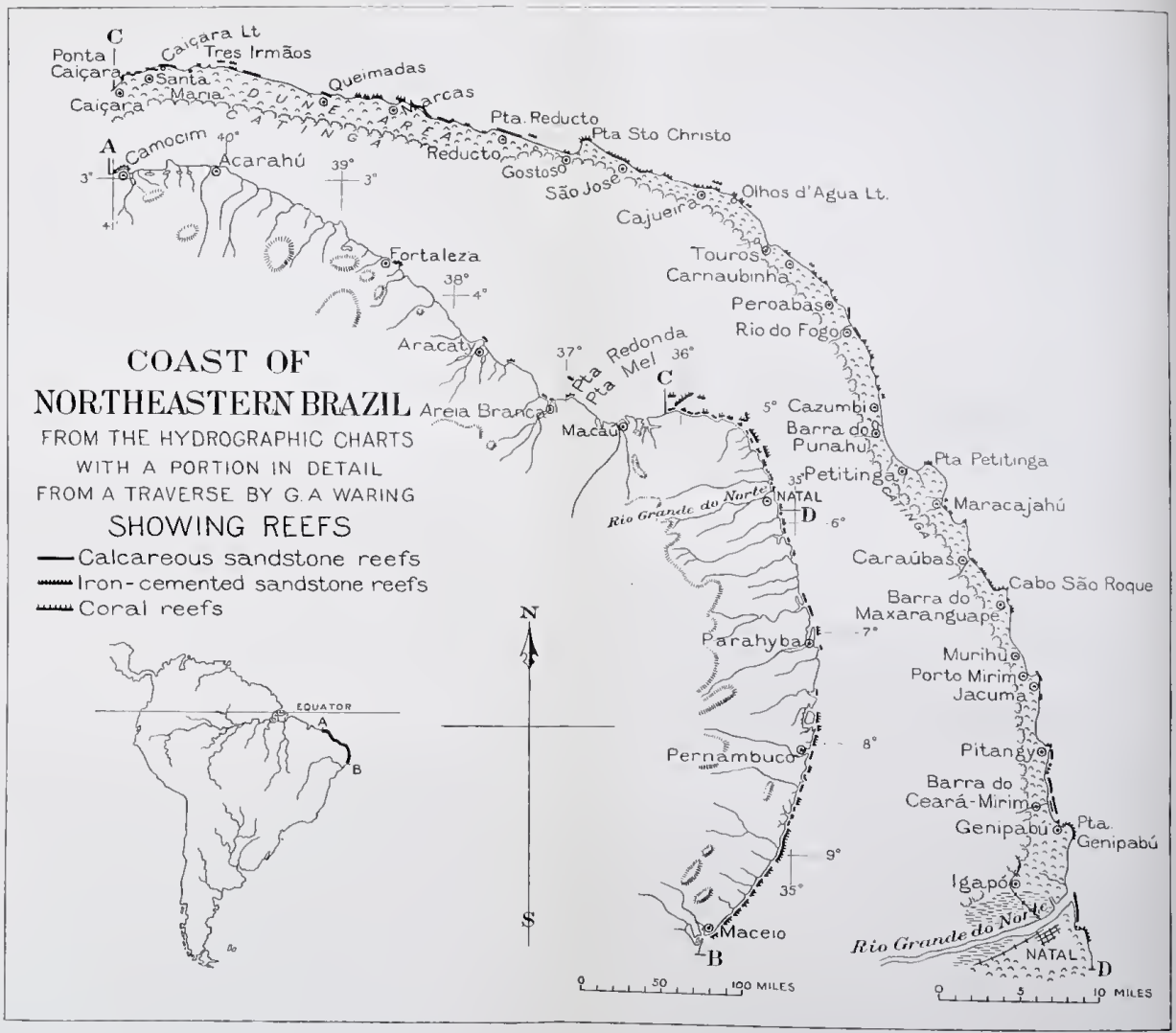
COAST OF
NORTHEASTERN BRAZIL
FROM THE HYDROGRAPHIC CHARTS
WITH A PORTION IN DETAIL
FROM A TRAVERSE BY G. A WARING
SHOWING REEFS
Calcareous sandstone reefs
Iron-cemented sandstone reefs
Coral reefs
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Caiçara
Queimadas
Pta. Reducto
Pta Sto Christo
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AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

Art. XXX.—*Reef Formations of the Northeast Coast of Brazil;* by Gerald A. Waring. With Plate IX.*

Location and character of the region.
Calcareous sandstone.
Reefs.
General features.
Mode of formation.
Reefs north of Rio Grande do Norte.
Other occurrences of calcareous sandstone.
Iron-cemented sandstone.
Cliffs.
Reefs.
Coral reefs.
Summary.

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Location and Character of the Region.

Lying wholly within the tropic zone, northeastern Brazil forms the shoulder of the South American continent. To the northwest is the Amazon region, noted for its abundant rains and tropic vegetation. To the south also the country is well supplied with water; but the region between about 3 and 15 degrees S. lat. is arid and is subject to periods of great drought. Few rivers drain this area, and except for a narrow belt along the coast, water is scarce during the greater part of the year. All of this coastal extent is low. For many miles the shore is bordered by sand dunes, which extend back a few miles to a gently rising plain, covered with a stunted forest of tall brush and cactus, and interrupted here and there by small isolated peaks and mountains. There are few settlements other than fishing villages along this barren stretch of coast. Nearly all the streams that enter the ocean discharge water only during

* The writer is indebted to Dr. J. C. Branner for encouragement in the preparation of this article.

periods of storm, and are hence of uncertain flow; for as is true in other arid regions, the rainfall of northeastern Brazil is very irregular in amount and distribution.

Calcareous Sandstone.

Reefs. *General features.*

At certain places along this coast there are sandstone reefs whose character and appearance is considered by scientists and others who have seen them to be almost unique. The only other known occurrences of a similar formation appear to be at a few places along the eastern shore of the Mediterranean and on the borders of the Red Sea, and little information is available concerning the reefs of these localities. The best known reef on the Brazilian coast is that which protects and in fact forms the harbor of Pernambuco, in about 8 degrees south latitude. This reef has been described or mentioned by numerous writers. In 1836 Charles Darwin in writing of it said that "at first sight it is difficult to credit that it is the work of nature and not of art."*

Dr. J. C. Branner, President of Stanford University and head of its geological department, who has worked on the geology of Brazil for many years, has published an exhaustive study of the reefs.† The principal features of the reef have also been summarized by him in a later paper,‡ and may be stated as follows:

The reefs are long, narrow, and nearly straight, and are situated in most instances near the mouths of streams and nearly parallel to the present beach. At some places where reefs have been formed, the reef is not connected with the land; in other places one end is exposed on the beach or is buried beneath the sands, while in still others the reef lies as a whole along the present beach. The axis of each reef is practically horizontal and lies at about high-tide level. Its top, however, slopes gently seaward and in section the material also exhibits bedding planes that dip at low angles toward the sea. While the better-developed reefs are as a rule nearly continuous, in many places they are cracked, broken and undermined by the surf, and many of the smaller reefs have been greatly broken up by this means. The lithified material is only ten or fifteen

* Journal of Researches into the Geology and Natural History of the various countries visited by H. M. S. Beagle . . . from 1832 to 1836. London, 1839, p. 593.

† The Stone Reefs of Brazil, their geologic and geographic relations, with a chapter on the coral reefs, Bull. Mus. Comp. Zoology, vol. xliv, Geol. Series vii, Cambridge, 1904.

‡ Stone Reefs on the Northeast Coast of Brazil, Bull. Geol. Soc. Am., vol. xvi, pp. 1–12, Feb., 1905.

feet thick at most, and is underlain by the usual coastal sands and clays. The outer edge of a reef is in many places nearly vertical, due to the breaking off of masses which now lie beside it in inclined positions and partly protect the exposed face from the force of the surf. The inner face is commonly broken much less, but its edge is irregularly etched. In many places the surface of the reef is also deeply etched into fantastic points and pinnacles, and contains shallow pools; but ordinarily it is fairly smooth and is partly covered by organic growths, which are more abundant near the seaward edge.

The material is a sandstone that contains quartz grains, with occasional beds of pebbles, a little mica, and shells and other organic remains in varying amounts, all being firmly cemented together by lime carbonate. The material is mainly so hard that it rings under the hammer and fractures across the quartz grains and pebbles; but in some places it is relatively soft. The shells appear to be those of kinds at present living in the adjacent water, and the other constituents of the rock are those of the present beaches.

Mode of formation.

Difference in hardness seems to be the only important feature that distinguishes the material of the reefs from that of the beaches. The conclusion, therefore, is that the reefs are beaches or sand spits lithified in place. This origin of the reefs and their mode of formation was worked out by Dr. Branner after a detailed study of the various reefs south of the port of Rio Grande do Norte. The various phases of the problem are treated fully in his publication on the subject,* and his conclusions can only be summarized here. The main features brought out by his study are as follows:

The reefs are in reality hardened beaches or spits, that have been encroached upon from both sides by the sea. Their straightness implies that the original beaches or spits were straight, and seems to be well accounted for by the usual process of straightening of an irregular shore line by the cutting down of headlands and the filling of embayments. The natural features of the coast, notably the lack of good harbors, the presence of low headlands which protect shallow bays, and of stream mouths partially or wholly closed by sand bars, are some of the factors which point to this conclusion. The reefs are therefore believed to be portions of mature, nearly straight, beach lines. The lime carbonate that hardened these beaches appears most probably to have been dissolved from calcareous beach sands by streams entering behind them, and to have been redeposited along the zone of contact with the salt water as the fresh water percolated seaward through these

* Bull. Mus. Comp. Zool., Geology, vii, 1904.

sands. The solvent action of the fresh water for lime carbonate was increased by organic acids derived from decaying vegetation, and the redeposition of the lime was mainly due to the inability of the increasingly salty water to hold it longer in solution.

The conditions necessary to such an hypothesis are all present along the coast where the reefs exist. The annual rainfall is so irregular in amount and distribution that the streams carry little or no water during a large part of the year and their outlets become partially or wholly closed by drifting sand. Vegetation, especially the mangrove and the water hyacinth, grow luxuriantly in the tidal portions behind many of these closed river mouths, and the decay of dead leaves and other fragments of vegetation doubtless charges the water with organic acids. This water gradually escapes to the sea by percolation through the sands that block the way, and at times by flowing long distances around the ends of sand bars. The sand contains many fragments of shells, coral and other calcareous animal remains, so that it may easily yield the requisite lime carbonate for the cementing process. Studies made by the Challenger expedition have shown that the ocean water is unusually dense in an area that borders the Brazilian coast approximately along the portion where the reefs are found.* This greater density of the ocean water tends to cause more rapid deposition of the lime, due to the inability of the dense water to readily hold it in solution, and is believed to be another important factor which caused the formation of the reefs.

Reefs north of Rio Grande do Norte.

The structure and the mode of formation of the reefs have been thoroughly discussed by Dr. Branner, and the present paper is not written in an attempt to add anything to his conclusions in those respects. Dr. Branner's studies, however, were confined to the reefs at and south of Rio Grande do Norte, and as in February, 1913, the writer traversed a portion of the coast north of that port, the following notes concerning the region are presented. These notes are intended mainly to record the calcareous sandstone reefs noted, but observations on the other kinds of reefs seen are also given.

The harbor at Rio Grande do Norte is formed by an especially well-developed reef, descriptions of which have been published.† Since no reefs equalling it in development were seen farther north, the illustration (fig. 1) is here presented, for

* Challenger Reports, Physics and Chemistry, vol. i.

† The stone reef at the mouth of the Rio Grande do Norte, by Dr. J. C. Branner and C. E. Gilman, American Geologist, Dec., 1899, pp. 342–344. The stone reefs of Brazil, by J. C. Branner, Bull. Mus. Comp. Zool., Geol. Series vii, pp. 35–39, 1904.

together with the representation of this reef on Plate IX, it well brings out two characteristics of the better-developed reefs, i. e., their relations to present beach lines, and their positions relative to stream mouths.

North of Rio Grande do Norte the first typical calcareous sandstone was found at the mouth of Rio Ceará-Mirím, where a double reef of the material is exposed at low tide (fig. 2). The two reefs are parallel, about 100 yards apart and curve

Fig. 1.

Fig. 1. Reef at mouth of Rio Grande do Norte.

gently with the present beach. The inner reef is the shorter, and some parts of it project only a few inches above the sand of the flat beach that is laid bare by the receding tide. Its rock is brighter in color and softer than the usual pale yellow to gray material, but otherwise it has the appearance of the typical reef rock. It is the most probable example noted of a recently formed deposit. A tidal lagoon, fringed with mangrove, is formed behind a bar which separates it from the beach. The outer reef consists of the usual hard, gray material. About 450 yards beyond the place where its northern end disappears beneath the water, another stretch of the same material, probably its continuation, appears close to the shore and extends around a gently curving beach, gradually receding and disappearing beyond the surf.

Proceeding northward, the reef rock next appears as a few scattered blocks in the surf about one mile south of a low point near the village of Pitangy. About 500 yards beyond these blocks, the material is exposed as a continuous reef, with bed-

ding planes dipping 3 degrees seaward, and lies partly as a barrier, partly along the beach, suggesting that a little bay has been washed out behind it as shown in fig. 3*a*. Its northern end is buried in the beach.

Near the village of Jacumá, a few miles northward, a small reef of the rock extends from the beach into the surf. At a low point beyond, a similar reef, which first appears in the water, extends in a straight line in such a direction that it

Fig. 2.

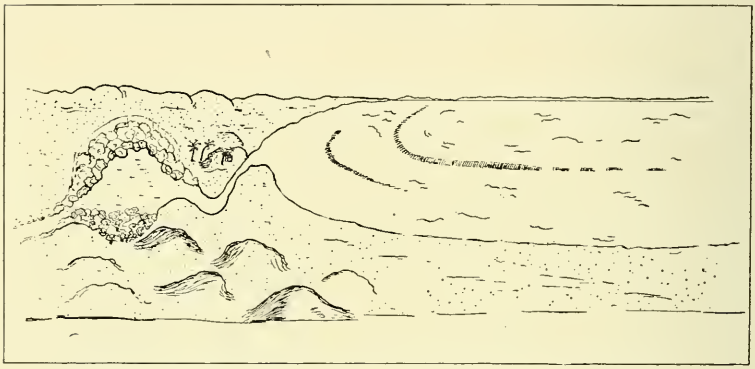


Fig. 2. Bird's-eye view of reef at mouth of Rio Ceará-Mirím.

passes for some distance along the beach and then disappears in the water beyond the point (fig. 3*b*).

No signs of a calcareous sandstone reef were found near the mouth of Rio Maxaranguape, $4\frac{3}{4}$ miles farther north, though this stream has a small perennial flow and contains much mangrove in its lower portion. The South Atlantic equatorial current flows westward from Africa and divides at Cabo São Roque, part going northward and part southward along the Brazilian coast. The southward-flowing current may have been of influence in preventing the formation of a calcareous sandstone reef at the mouth of the Maxaranguape, which is only one mile south of the cape. The position of the Maxaranguape, near a projecting part of the coast, also appears not to be favorable to the formation of a calcareous reef, for nearly all of the prominent reefs described by Dr. Branner extend along inward-curving beaches, northward from river mouths.*

* This characteristic is well brought out by the several detailed maps of reefs accompanying Dr. Branner's report (Bull. Mus. Comp. Zool., vii, 1904). The northward discharge of river mouths, produced by drifting sand, is mentioned by Olaf Pitt Jenkins, Geology of the Region about Natal, Rio Grande do Norte, Brazil, Proc. Am. Phil. Soc., vol. lii, No. 211, p. 4, Sept.-Oct., 1913.

The first observed occurrence of the typical reef rock north of Jacumá is near the mouth of Rio do Fogo, 24 miles away in a direct line. About one-half mile north of the mouth of this small stream a reef of the usual material appears off-shore and trends N. 20° W. (mag.) while the beach trends N. 6° W. Hence after a short distance the reef attains the beach, at a

Fig. 3.

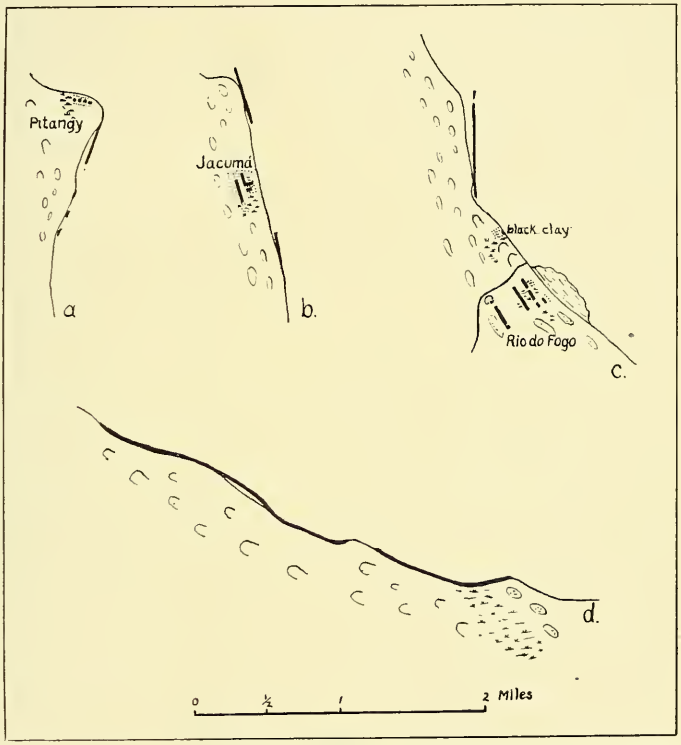


Fig. 3. Positions of calcareous sandstone reefs relative to the present beach: *a*, near Pitangy; *b*, near Jacumá; *c*, near Rio do Fogo; *d*, northwest of Ponta Reducto.

place where the beach turns a little more to the west (fig. 3*c*). At this place the reef also turns, but at an angle instead of in the nearly universal gentle curve, and bearing N. 16° W., extends for about six-tenths of a mile in a straight line nearly parallel with the beach, finally disappearing in the surf. A reef which is exposed for a width of 200 or 300 yards at low tide and extends for some distance southward from the mouth of Rio do Fogo, appears to consist of quartz grains cemented

by calcareous material. It is pale yellow in color and is possibly an example of recent cementation, though it does not closely resemble the more typical reef north of the stream's mouth. Rio do Fogo has only a slight flow during the dry season, and at present does not support a growth of mangrove; but a bed of black clay exposed in the beach near its mouth resembles the material of mangrove swamps. The relative positions of the stream mouth, the bed of clay and the typical reef to the north suggest that the stream formerly entered the ocean somewhat farther north, while the wide reef of calcareous sandstone to the south suggests that more recently its water may have sought the ocean in that direction. Sand dunes now crowd the stream channel back from the shore and absorb most of its water, which reappears in part nearer the beach in the form of small springs.

Two miles north of Rio do Fogo, large slabs of the typical rock are exposed at low tide, lying upon iron-cemented sands at a small point near the village of Peroaba, while two reef fragments 200 or 300 yards long are seen respectively $1\frac{1}{2}$ and $1\frac{3}{4}$ miles northward, at about half-tide level, partly buried in the beach.

Continuing along the beach, a few other masses of the rock are to be seen in several places firmly cemented to red, iron-cemented sandstone that forms fringe reefs, but the next typical reef is met near Ponta Reducto, a number of miles farther to the northwest. The rock here appears abruptly in the surf and owing to the slight curve of the shore soon reaches the beach. Thence the reef rock extends along the beach, in large part as broken slabs piled up beyond ordinary high-tide level, for a distance of $1\frac{3}{4}$ miles, to the southeastern end of the point, where at low tide it is seen to be firmly cemented to the red sandstone at the base of the bluff. In the cove beyond the point a few slabs of the rock appear, and again at a wide curve of the low beach $1\frac{1}{4}$ miles farther northwest. Near the next curve of the beach, one mile beyond, the material appears on the shore above high tide, extends along the upper border of the beach as a succession of broken slabs, and disappears beneath a small sandy point. It reappears on the other side of this point, however, and continuing partly in the water but mainly along the upper part of the beach, it finally disappears landward (fig. 3*d*). The total length of this reef, including the portion hidden by the sandy point, is fully 3 miles.

The calcareous sandstone is next seen 5 miles westward, at a place called Queimadas. Here from an inward curve of the beach line, a narrow reef extends into the water for perhaps 300 yards. It appears for a few yards on shore as a confusion

of broken slabs, while bands of shells and disintegrated fragments of the rock in the sand back from the beach mark the buried eastward continuation of the reef. Westward also, beyond the extremity of the reef, shells and disintegrated fragments of reef rock may be found at a distance of 50 to 100 yards from the present beach, for a couple of miles along the undulating sandy plain.

About 3¾ miles west of Queimadas the reef rock begins again abruptly on the beach within reach of the tide. A spring of fresh water gushes up from beneath its extremity, and 450 yards beyond this spring another rises through the beach sand at about half-tide level, probably from beneath a buried block of the reef. Thence the reef continues, principally as great loosened blocks and slabs, along the beach at half-tide to high-tide level, for 1½ miles to the eastern end of the series of cliffs known as Tres Irmãos (Three Brothers). In the cove between the eastern two headlands and also at their bases a few blocks of the reef rock are visible at half-tide, the gray or pale yellow of the latter contrasting with the dark red sandstone of the cliffs.

A few miles west of Tres Irmãos and 1½ miles east of Caiçara light, in the sandy plain 80 yards from the beach and approximately parallel with it, there is an exposure of disintegrated calcareous reef rock, part rust-colored, part bleached, about 5 yards wide and 50 yards long. It is perhaps the best example that was seen of an inland remnant of a reef. About one-half mile westward from this remnant the rock reappears as broken slabs half-buried in the beach, but soon becomes a continuous beach-reef, with blocks of the material piled in confusion along its landward edge. The Caiçara light post is erected on a concrete foundation built on the reef at high-tide level. A small headland that rises to a height of 20 or 25 feet just west of the light is composed of fluted and craggy, lime-cemented sandstone that resembles the calcareous reef rock, while over the sandy knolls behind the headland are scattered many shells, fragments of coral, and pieces of lime carbonate that resemble calcified brush roots. From among these knolls a low ridge of gray to rust-colored, disintegrated lime-cemented sandstone, with many loose shells lying along its course, leads westward down to a small reef that disappears in the water of a little bay. On the far side of this bay, a short distance west of the fishing village of Santa Maria, the reef again appears in the surf. The beach thence to Ponta Caiçara, a distance of 1¾ miles, is very nearly straight. The reef rock, however, after attaining the beach and following it for 550 yards, swings a short distance inland and becomes nearly buried for 100 yards. It then returns and again forms

a beach-reef for 850 yards farther (see fig. 4), and then swings landward and is lost, though its course may be traced for some distance farther by scattered and disintegrated fragments 25 to 50 yards back from the beach. The relation of the reef to the beach along this stretch is shown by figure 5. Ponta Caiçara is formed of fresh-looking, pale-yellow, very hard stone which closely resembles the reef rock. The exposure at this place has not the usual long and narrow form of the typical

Fig. 4.

Fig. 4. Lithified beach near Ponta Caiçara.

reefs, however. The material extends from the base of a large dune down to the surf, where it exposes a steep face to the beach for a few yards. The western end of the lithified mass terminates abruptly in a vertical face 6 or 8 feet high that trends straight inland and disappears beneath the drifting sand 100 yards from the beach. The dip of the material here exposed seems to be about 10 degrees to the northeast, while the beach-reef farther east dips at low angles uniformly northward, into the sea.

The reef or lithified beach that extends almost uninterruptedly from some distance east of Caiçara light to the point of the same name, appears to be the westernmost area of any considerable extent of the typical calcareous reef formation.

By reference to the general map of Plate IX it will be seen that no streams of importance drain the area between the courses of Rio Ceará-Mirím and Rio Salgado (which enters tide water at Macáu). None of the small streams that enter the ocean between these two rivers have calcareous sandstone reefs at their mouths. The reefs that are present along this

part of the coast, however, are in several places situated in suggestive relation to existing areas or lagoons or marsh land, shut off from the sea by dunes of sand. This seems to be shown near Rio do Fogo (fig. 3*c*), and also near Ponta Reducto. At the latter place the present position of lagoons, as shown by figure 6, is evidently determined by the shifting sands; and conditions might easily have been such as to cause the water to find outlet in the vicinity of the present reef.

All of the well-developed reefs noted by Dr. Branner south of and including Rio Grande do Norte are opposite the

FIG. 5.

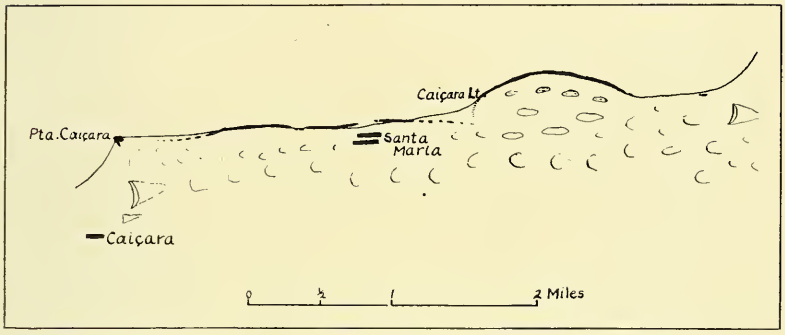


FIG. 5. Relation of lithified beach to present beach, near Ponta Caiçara.

mouths of rivers of considerable flow. In the light of the origin of the reefs, the absence of such well-developed off-shore reefs farther north may, therefore, be safely ascribed chiefly to the absence of suitable streams for their formation; for the weak flow of fresh water seaward has apparently been able to harden masses of sand only along the beach. In some places, however, these consolidated beaches have been encroached upon by the sea, so that they now form off-shore reefs.

The apparent greater frequency of reef remnants along the shore northwest of Touros than southward from that place is perhaps due directly to the curving of the coast line in this vicinity to a more northwesterly course. This brings the beach line more nearly parallel with the direction of the prevailing wind and hence induces slight alteration of the beach line by the drifting sand. The best example of this phenomenon that was noted is in the vicinity of Ponta Caiçara, and has been already described.

Other Occurrences of Calcareous Sandstone.

Although the materials of the headland near Caiçara light and of Ponta Caiçara are similar in composition to those of the well-developed reefs, they resemble hardened masses of sand rather than elongated spits, and this character is exhibited by other occurrences that were noted farther west.

The first one of these occurrences is 6 miles west of Ponta Caiçara, at Ponta Jacaré. Here the typical gray, lime-cemented sand with layers of gravel and shells is exposed for about 100 yards along the beach; but instead of forming a reef or a lithified beach, the rock extends from the base of a

Fig. 6.

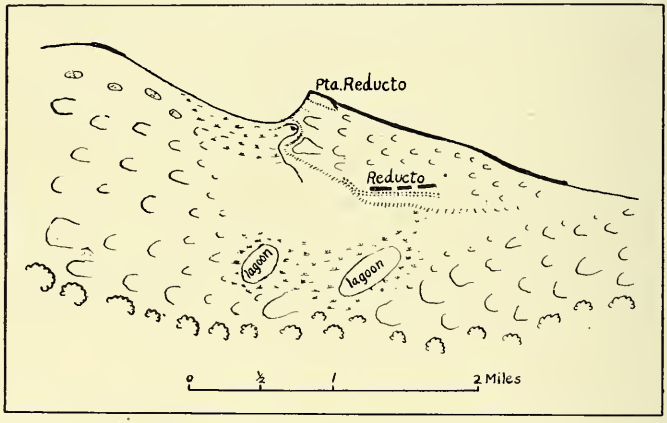


Fig. 6. Region near Ponta Reducto, showing relation of lowlands to the reef.

great sand dune to the water 25 yards away, where it forms a ledge 5 or 6 feet above half-tide level and dips 8 degrees to the north, seaward. This is the westernmost exposure of the reef rock that was seen along the beach in the journey between Rio Grande do Norte and Macáu. It could not be definitely learned by inquiry whether or not rock is exposed along any part of the coast between Ponta Jacaré and Macáu; and this portion of the coast, which is low and intersected by tidal inlets, was not traversed. It is believed, however, that no reefs are present along this stretch of dunes and tidal inlets.

At a few places west of Macáu the calcareous sandstone was observed near ports that were visited on coasting steamers, the first one west of Macáu being Areia Branca. Along the ocean east of the entrance to this port the beach is bordered

from an inlet know as Barra do Upanema nearly to the Areia Branca lighthouse, a distance of $1\frac{1}{4}$ miles, by gray, lime-cemented sandstone. This is composed mainly of coarse sand and small pebbles. No shells were seen imbedded in it, though a few seams are filled with lime-cemented shells and pebbles. While it resembles the usual reef-forming material, at many places it extends from the bases of dunes for a number of yards to the surf, and therefore is not considered typical reef rock. A few fragments of the rock, more or less disintegrated, are also exposed between the dunes.

FIG. 7.

FIG. 7. Undercut cliff of lime-cemented sand near Fortinho.

Morro Thibáu is a hill which borders the shore about 6 miles northwest of Areia Branca. Part of its coastal side is bordered by a cliff 15 to 30 feet high, behind which sandy slopes rise to a maximum height of 160 feet. A number of small springs of fresh water issue along the upper border of the consolidated layer that forms the cliff. This layer is composed of gray to red-brown sand in which are occasional chalky masses the size of an egg. A reef of the same material borders the cliff, and though it does not closely resemble the typical lime-cemented reef sandstone, it appears to have a similar mode of origin and to be comparable with the small cliffs at Pontas Jacaré and Caiçara and at Caiçara light.

At Fortinho, the port of Aracatý, gray, lime-cemented sandstone underlies cliffs of red, sandy clays, partly as a shelf at about high-tide level, and partly as a low cliff which is deeply undercut at one place (see fig. 7.) The lighthouse at the

entrance to this harbor is built on low slopes of brick-red sandstone, but at the beach about a mile beyond the light there is a cliff, 15 or 20 feet high, whose material from a distance resembles the gray rock at Fortinho. Although this calcareous sandstone of the port of Aracaty does not form the typical low, narrow reefs, it does resemble the sandstone of Ponta Caiçara.*

The presence of a sandstone reef in the harbor of Fortaleza is mentioned in a report on the betterment of the port, published in 1875.† The reef described is apparently in the locality now occupied by a breakwater that was built in an unsuccessful attempt to form a quiet harbor. No evidence of a reef was seen along this wall in 1913, but small areas of iron-cemented sand and gravel along the neighboring shore indicate that the reef is of this material rather than of calcareous sandstone. At two places along the beach between Fortaleza and Ponta Mucuripe, 4 miles to the east, however, small masses of fine-grained, very firmly-cemented gray to pale-yellow beach sand were seen, partially buried at about half-tide level; while near the point, similar small masses of hard, fine-grained sandstone are firmly cemented to the red iron-sandstone in cavities and seams, where the sand has evidently been blown from the adjacent dunes by the wind. It would appear that under favorable conditions small masses of beach sand deposited on the iron-cemented sands may become firmly consolidated by calcareous material.

On the western side of the harbor of Camocim several blocks of the typical calcareous sandstone are exposed on the beach $\frac{3}{4}$ to 1 mile north of the northernmost shipping pier. Although it is situated well within the river mouth which forms the harbor, the material very closely resembles the typical reef material in texture and composition. It does not form banks or cliffs, as does the calcareous material at Fortinho. The occurrence of calcareous sandstone at Camocim is the westernmost that was seen by the writer. There is none for a distance of 8 miles farther west along the coast from this city, and though small patches may exist beyond, inquiry among the fishermen at Camocim failed to yield any information on the matter. The material was not observed at the harbors of Amarração, Tutoya and Maranhão, respectively 60, 100 and 250 miles west of Camocim.

* At several places on the beach behind the sand bar which prevents small coasting steamers from entering the harbor at Fortinho except on the highest tides, black clay, the remnant of a mangrove area, is exposed, and resembles at a short distance a low reef.

† Melhoramento dos Portos do Brazil, Relatorio de Sir John Hawkshaw, pp. 89–91, Rio de Janeiro, 1875.

Iron-Cemented Sandstone.

Cliffs.

Practically the entire coast northward from Rio Grande to Norte is bordered by the red and parti-colored sands and sandy clays, probably of Tertiary age, which also border the coast for many miles southward from that place. Along perhaps the greater part of the coast to the north these colored sediments are obscured by drifting beach sands, but in many places they form cliffs which, though ordinarily less than 50 feet in height, are prominent features of the low coast line. The limestone which underlies these sediments and is exposed a few miles inland, is seen near the beach at only two localities. One locality is near Fazenda As Moças, 25 miles east of Macáu and $1\frac{1}{4}$ miles from the beach, where a flat surface of hard, gray, fossiliferous stone is exposed over an area several hundred yards in diameter, beyond the extremity of a tidal inlet. The other exposure is 8 miles farther west, in the channel of another tidal inlet, at the base of a low bluff of the colored sediments.

In several places, notably at Tres Irmãos, the sedimentary cliffs form headlands against which the surf beats, but in other places they are not prominent features on the map. In the reëntrant a few miles northwest of Cabo São Roque, cliffs of the red sediments rise from the surf to heights of 20 to 30 feet, but at the cape itself there is no cliff. Large knolls of light-colored sand, partly brush-covered, trend uniformly northwest at this place, while the beach around the cape is protected by a wide fringe reef of iron-cemented sand. The material of the coastal cliffs varies in character from place to place and in the several layers exposed in a single cliff. The various shades of yellow and red-brown due to iron prevail, but in some places the material has a mottled appearance caused by small patches of white or pale-yellow sandy clay in the mass. It seemed to the writer that the prevailing color of the cliffs north of Rio Grande do Norte is considerably darker than is that of the cliffs south of this port. It is worthy of especial note that no shales were seen at any part of the coast north of Rio Grande do Norte, though shales are found at numerous places farther south.

The cliffs northwest of Cabo São Roque expose sections approximately as shown in figure 8*a* and *b*, while a low cliff 22 miles in a direct line northwest of the cape, between the villages of Peroaba and Carnaubinha, exposes cross-bedded sands as shown in figure 8*c*. Other cliffs northward, notably those at Touros, Ponta Reducto and Tres Irmãos, do not show distinct beds, the material being consolidated as a whole with only local differences in color, hardness and texture. These

local differences induce weathering into more or less fluted columns and into caverns.*

The highest cliff along the northeast coast of Brazil is that of Ponta Mel, between Macáu and Areia Branca, the lighthouse which stands on the point being nearly 300 feet above the sea. The cliff itself forms only the upper half of the point, rising above great dunes and winrows of sand, as is

Fig. 8.

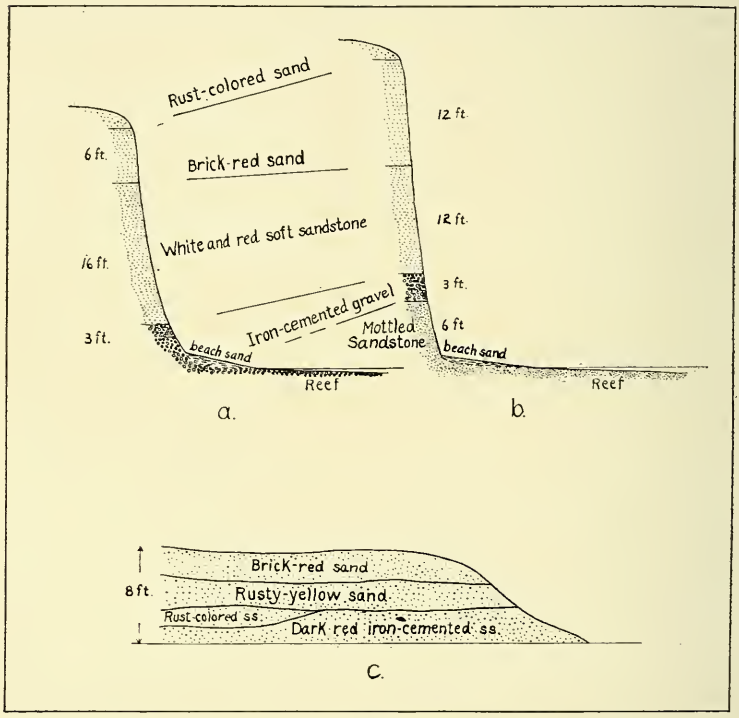


Fig. 8. Cliff sections: *a*, 1½ miles northwest of Cabo São Roque; *b*, 2¾ miles northwest of Cabo São Roque; *c*, 2½ miles northwest of Peroaba.

shown in figure 9. The section exposed is approximately as in figure 10. Ponta Redonda, a few miles farther west, is only 25 or 30 feet high. It is of mottled sandstone, mainly purple in color, but with markings of lemon-yellow and of yellow bordered by white. Caverns have been formed in the material,

*The cliffs at these places are similar to those near Natal, which have been described by Olaf Pitt Jenkins (Geology of the region about Natal, Rio Grande do Norte, Brazil: Proc. Am. Phil. Soc., vol. lii, No. 211, pp. 23–25, Sept.-Oct., 1913).

and the resulting protected surfaces are studded with subangular quartz pebbles up to an inch in size. Fallen blocks form a breakwater along the front of the cliff (fig. 11). These blocks contain numerous seams which are filled with pebbles and shells cemented together with lime carbonate, while a few seams ½ to 4 inches wide are filled with small, silvery-white mollusk shells closely matted together as if they had grown thus.

On the slopes behind the cliffs at Tres Irmãos the surface is dotted with fragments of calcified brush roots and branches.

Fig. 9.

Fig. 9. Ponta Mel as seen from a coasting steamer.

Some of the fragments attain the size of a man's arm, and many can hardly be distinguished by sight alone from the associated fragments of wood. This form of petrifaction appears to have been effected while the bushes were covered by dune sand, which has now drifted past and left them exposed again. Some calcareous matter has also penetrated downward into the sandstone of the cliff and is seen as lighter-colored masses. In the dune areas near Ponta Reducto and Ponta Mel similar calcified fragments were seen, less well-developed, and in a wide expanse of dun-colored dunes and sand knolls about halfway between Ponta Jacaré and Macáu, beyond the inland reach of the tidal inlets, considerable areas are dotted by whitened and sand-worn conch shells and by bone-white fragments of lime carbonate that resemble roots and twigs.

Reefs.

In practically every place where cliffs have been formed along the coast, a fringe-reef of the same material extends out into the water. In a few places there is very little difference

Fig. 10.

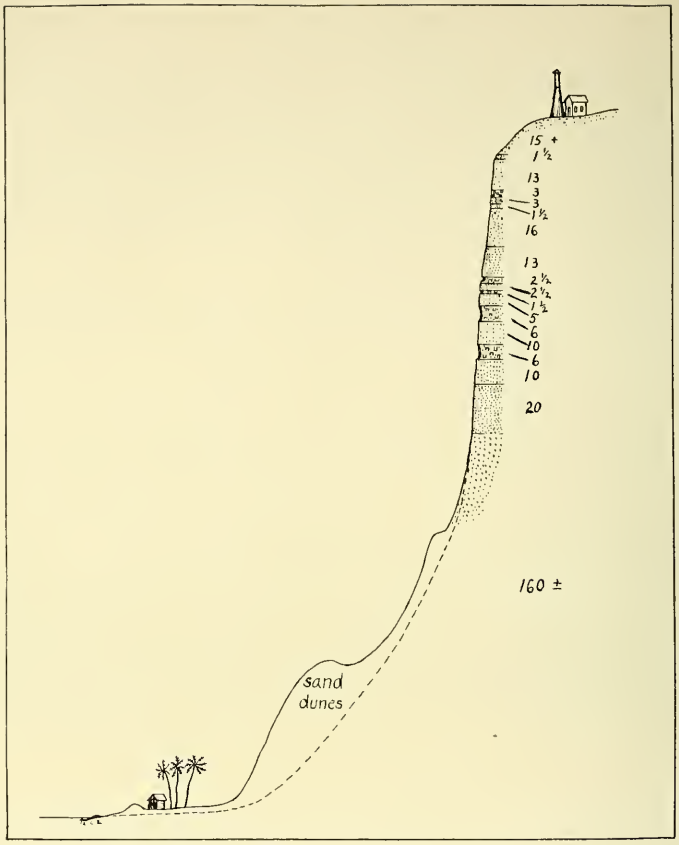


Fig. 10. Section of cliff at Ponta Mel.

Feet.	
15+	Red, sandy gravel.
1½	Rusty quartz gravel.
13	Red, sandy gravel.
3	Rusty quartz gravel.
3	Coarse, mottled sandstone.
1½	Purple sandstone.
16	Red, gravelly sandstone.
13	Reddish-purple sandstone.
2½	"Patterned sandstone."
2½	Reddish-purple sandstone.
1½	"Patterned sandstone."
5	Reddish-purple sandstone.
6	"Patterned sandstone."
10	Reddish-purple sandstone.
6	"Patterned sandstone."
10	Reddish-purple sandstone.
20	Purple sandstone.
160±	Probably brick-red and mottled sandstone, but obscured by dune sand. The lower slopes have many fragments of shells and of lime carbonate. A reef of mottled sandstone is exposed at low tide.
289½	

The "Patterned sandstone" differs from the usual mottled sandstone in having a mottling that somewhat resembles the crystal pattern on a polished surface of meteoric iron. The colors are lemon-yellow, white and pink, in a ground of bluish-purple. It is softer than the reddish-purple sandstone.

in texture and hardness between the material of the reefs and that of the cliffs; but in most places the reef-forming portion is harder, heavier and more nearly rust-color, and it appears that concentration of the iron has taken place in those places subjected to the action of the sea-water. In many places where the red sandstone is not in evidence as cliffs, reefs of the material are exposed along the shore, and probably the greater number of the reefs along the northeast coast of Brazil are of

Fig. 11.

Fig. 11. Blocks of iron-cemented sandstone at Ponta Redonda.

this material. The approximate extent of these reefs along the portion of the coast under consideration is indicated on the general map of Pl. IX. They are also present farther to the north and to the south. In many places the material is an iron-cemented gravel, rather than a sandstone; but it appears to be made up of fragments of the coastal sandstone, recemented together. The wide distribution of the iron-cemented reef-forming material is notable. It is exposed at the base of a cliff of light-colored sediments on the north side of the harbor of Maranhão, 250 miles west of Camocim, and extends far toward the channel of the harbor at low tide. At the immediate base of the cliff there are bowlders in which the iron is heavily concentrated. Even along the Amazon River the concentration of the iron at or about tide level seems to have taken place in the red sediments, as is shown notably at the base of a bluff on the north bank, 700 miles above the river's mouth, between the villages of Parintins and Itacoatiara.

In a few places, notably at Touros, Ponta Reducto and Tres Irmãos, the layer or zone that has been hardened by the concentration of the iron rises a number of feet above sea level, but in most places the hardened layer is only a little above high tide limit, as is shown in a reef near São José. The prevalence of the hardened material and its presence only at about sea level suggest that the concentration of the iron in the iron-cemented sandstone has taken place in similar manner to that of the lime carbonate in the calcareous sandstone reefs. In the case of the latter Dr. Branner has shown* that the lime is deposited along the zone of contact of the fresh with the salt water. Similarly, when fresh water that has percolated down-

Fig. 12.

Fig. 12. Iron-cemented sandstone reef near São José.

ward through the iron-impregnated sediments and dissolved a slight amount of the iron comes in contact with the salt water of the ocean, it probably drops its iron, which thus becomes concentrated at about sea level. It seems that some such action must have taken place in order to produce the extensive fringe-reefs of the material that are in evidence at places where landward the sediments are obscured by drifting sand. The fact that such concentration and cementing is still going on at about sea level appears to be shown at numerous reefs which are dotted with fragments of sandstone, all firmly cemented to the reef surface.†

At a few places a layer that has been hardened by concentration of the iron is also found in the red sediments some distance inland from the beach. Ponta Morcego, 2 miles southeast of the center of Natal (Rio Grande do Norte), is of iron-cemented sandstone in which the iron has been concentrated, and within

* The stone reefs of Brazil, Bull. Mus. Comp. Zool., Geol. vii, p. 193, 1904.

† This feature has been mentioned by Jenkins (Geology of the region about Natal), Proc. Am. Phil. Soc., Sept.-Oct., 1913, p. 24.

the city itself irregular masses of the material several feet thick are exposed in low bluffs near the harbor, a short distance above tide level. The material was also encountered at approximately sea level in nearly every one of about 50 wells that had been drilled in the upper part of the city prior to 1913; but so far as could be determined by examination of the well records, the material is thinnest in the wells most distant from the harbor. It was not encountered in wells sunk in the lower part of the city (below the exposures in the bluffs); neither was it met in a well sunk in the lowland across the harbor channel,* nor in excavations made to depths of more than 50 feet in the channel itself for the piers of a railroad bridge. At the farther side of a wide flat across the harbor from Natal the hard, iron-cemented material is exposed near the base of a red sandstone bluff, but a bed which appears to be a continuation of the material exposed in the bluff is seen to thin out landward, along a railroad cut which ascends the slope. About 20 miles south of Natal, in bluffs bordering a tidal inlet or lagoon, broken masses of the iron-cemented sandstone show the presence of a layer 2 or 3 feet thick, but on tracing it inland by occasional fragments along a railroad cut, their decreasing size indicates that the hardened layer rapidly thins.

A few miles east of Fortaleza much indurated iron-sandstone is exposed on the shore as low bluffs and fringe reefs. About $1\frac{1}{4}$ miles inland the material was encountered in a well at a depth of 6 feet, which well was continued to a depth of 16 feet without passing through it. This well is 300 yards from the margin of a tidal lagoon. The material is also exposed in a pit 100 yards nearer the lagoon, at a depth of only 2 feet, and although it was not found along the border of the lagoon, springs of fresh water issue a few feet above the margin, probably from about the upper surface of the impervious material.

The eastern side of the harbor of Camocim is bordered by large sand dunes that are continually encroaching on the water and effectually cover the underlying formation. To the west, however, the immediate coast is low, though backed by dunes, and is bordered for several miles by a nearly continuous reef of iron-cemented sandstone. Springs of fresh water issue at numerous places along the beach below high-tide level. There is a wide fringe reef of the sandstone along the beach near the Camocim lighthouse, but at the light, which is 175 yards back from the beach, good water is obtained at approximately sea level in a shallow well in which rock was not encountered. The well, however, is possibly not deep enough to determine

* A record of the materials encountered in this well is given in Jenkins' paper, Proc. Am. Phil. Soc., No. 211, pp. 28–29, 1904.

whether or not the iron-cemented rock exists at this place. Two wells that were drilled to depths of more than 50 feet at Camocim, 2 or 3 miles from the ocean and several hundred yards from the harbor, did not encounter iron-cemented material.

Although the evidence here advanced is slight, it is believed by the writer that the iron-cemented material which forms most of the fringe reefs and probably some of the off-shore reefs as well, is not a definite bed in the Tertiary coastal sediments, but is a hardened phase in them produced by the concentration of the iron; and that this concentration and hardening is limited to approximately sea level and extends only a short distance back from the shore.

Coral Reefs.

In addition to living coral reefs which exist off-shore between Rio Grande do Norte and Macáu, a few reefs that now join the land have their upper portions, at least, composed of dead coral material. These reefs are here noted chiefly to extend northward the records of Dr. Branner on the presence of such reefs and the evidence that they furnish of a comparatively recent slight elevation of the coast. The corals can have grown only when they were under the ocean water most of the time, and the presence at some places of their remains entirely out of water shows that the coast at those places has been uplifted a sufficient amount to bring the corals into their present position relative to sea level.

An organic formation that is not coral but which seems worthy of mention is a soft stone formed by worms that cement together grains of beach sand. This material was observed at only two places: on blocks of iron sandstone on the beach at Ponta Morcego, and to lesser extent on rocks at Ponta Genipabú a few miles northward. Dr. Branner mentions having observed the material farther south, it being especially well developed near Bahia Formosa, 45 miles south of Ponta Morcego.

The outer portion of the fringe reef at Ponta Genipabú is overlain by flat-topped masses that are covered to a thickness of several inches with brown, calcareous tubes and the remains of other forms of sea life. It is the only reef where such material was seen. The main part of the reef is, however, of the common iron-cemented sandstone.

About three miles westward from the village of Cajueira a bluff which rises at the upper edge of the beach to a height of 8 or 10 feet exposes for several yards a cream-colored to rust-colored rock that apparently consists of quartz grains cemented

together by the remains of coralline animals. A smaller amount of this same material was noted on the surface of a wide reef of iron-cemented sandstone about two miles farther northwest, within the reach of high tide. Similar material forms a reef near Marcas, 16 miles farther west, but at this latter place it is more firmly consolidated.

Ponta Santo Christo is bordered by a low reef of compact, pale-yellow coral that joins the beach and is uncovered for a width of several hundred yards at low tide. No iron-cemented sandstone was seen at the point, but within the cove westward from it the usual sandstone is exposed.

The point near the little settlement of Marcas is fringed by a wide reef of hard, pale-yellow to cream-colored rock that appears to be of quartz grains and pebbles cemented by coralline remains. No other rock was noted beneath it. At low tide the material is uncovered for fully half a mile westward from the beach, in a small cove or bay, and stands about two feet above the water. Beyond the cove the reef reappears along the shore for several hundred yards and extends 200 or 300 yards seaward at low tide. This western portion consists of compact pale-yellow coral containing a few fossil shells* and a very little sand. It is the westernmost coral formation that was seen along the coast.

Summary.

In addition to the observations on various reefs north of Rio Grande do Norte which are given in the preceding pages, an attempt has also been made to incorporate those points of wider interest which were noted concerning the geologic features exhibited. These may be summarized as follows:

1. Off-shore reefs of calcareous sandstone are less well-developed north of Rio Grande do Norte than they are south of that place. The principal cause for this absence of prominent calcareous reefs in the northern region is believed to be absence of streams of considerable size entering the ocean. Beach reefs or lithified beaches, however, are more common northward, for the fresh water that slowly percolates from the land to the shore encounters the salt water at the beach. The tendency has therefore been for it to deposit its lime in the beach sands, and this action has taken place on a considerable scale where lithified beaches have been formed.

2. Beyond where the coast swings from a northerly to a westerly course, inland remnants of reefs and lithified beaches become more common, as the prevailing westerly wind there

* The two best-preserved shells were kindly identified by Dr. W. H. Dall as *Leptothyra albida* Watson, and *Botula cinnamomea* Lamarck, both being of species living at present in the Antilles.

becomes more effective in making slight alterations in the beach line, and in some places has built out the beach beyond what its position was at the time of its lithification.

3. Ponta Caiçara marks the western limit of the typical reefs or lithified beaches, but at a number of localities farther west similar hardening has taken place.

4. The iron-cemented Tertiary sands and clays border the coast for practically the entire distance between Rio Grande do Norte and Camocim. (They also extend along the coast for many miles beyond these points.) At a number of places the sediments form relatively low but prominent cliffs, but for long stretches they are obscured by beach sands. The limestone that underlies the sandy sediments was observed in only two places, near each other. Shales were not seen at all.

5. Dead coral reefs attached to the land were seen at a few places, the westernmost being a short distance beyond Marcas. They furnish unquestionable evidence of slight elevation of this portion of the coast.

U. S. Geological Survey, Washington, D. C.

Art. XXXI.—*Note on a New Meteoric Iron from Mount Edith, Ashburton District, West Australia;* by W. M. Foote.

This meteorite was found April 20th, 1913, by Mr. James Bourke of Boolaloo Station, Ashburton, W. A. Mr. Bourke

Fig. 1.

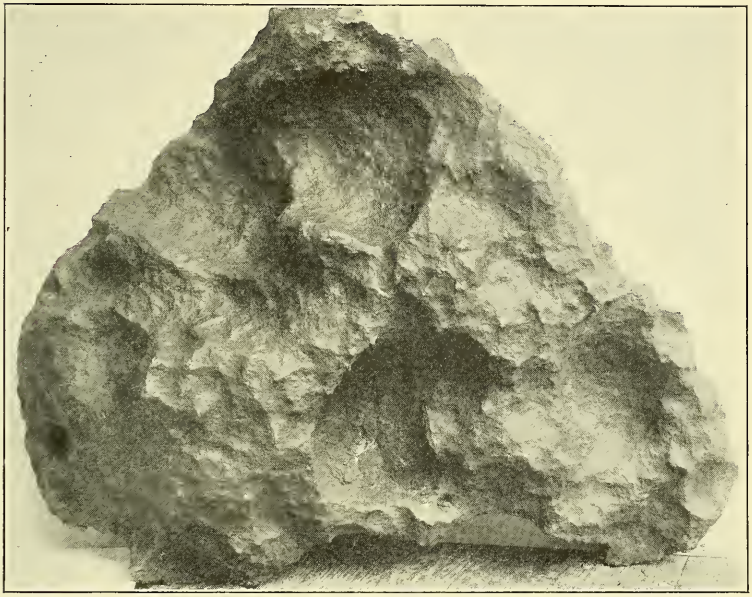


Fig. 1. Deeply pitted side. × 1/6 diameter.

states that it was met with in the country schist, buried in an upright position; about five inches of the thinnest edge showed above the surface. The locality is near Mount Edith, which is situated in 116° 10′ E. and 22° 30′ S., being well within the tropic of Capricorn. About 80 miles to the northwest is the post town of Onslow and about 160 miles to the northeast is another coast town, Roebourne. There is no record of other meteoric finds nearer than that of the Roebourne iron 100 miles distant. For the foregoing data I am indebted to Mr. Harry P. Woodward of Perth, W. A. The mass was

recently acquired by the Foote Mineral Co. of Philadelphia. It is proposed to designate the fall as "*Mount Edith.*"

The meteorite weighed complete, 161 kilograms or 355 pounds avoirdupois. Its average dimensions are about $45\times40\times12^{cm}$ ($18\times16\times5$ in.) and its overall dimensions $62\times55\times20^{cm}$ ($25\times22\times8$ in.). It has an irregularly triangular flat

Fig. 2.

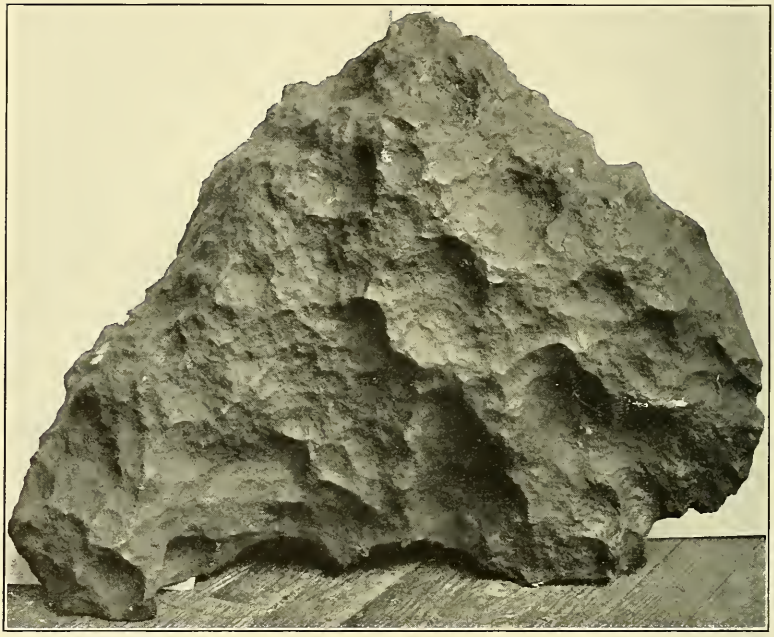


Fig. 2. Broadly pitted reverse side. × 1/6 diameter.

shape, suggesting a broad Indian arrow-head. In figs. 1, 2, 3, the blunt point of the arrow-head is at the top, the thin rear edge at the bottom. The center of gravity being nearer the thickest point, and this being deeply imbedded in the rocky ground, was probably the front in flight. The long thin edge would thus form the rear in flight. Such an orientation may be further confirmed by the fact that with a fairly uniform distribution of hard schreibersite and troilite throughout the mass, the iron is very much harder in the front than in the middle or rear. It requires three to four times as long to saw

through a square inch in the former area as in the latter. One explanation of this variation is that the front, being subjected to greater heat during the atmospheric passage, was tempered to a slight depth below the surface.

One of the two broad sides (fig. 1) is marked by four nearly hemispherical pits about 12 to 15^{cm} across and 7 to 8^{cm} deep,

FIG. 3.

FIG. 3. View outlining pits. × 1/6 diameter.

the central one at the rear almost perforating the mass. At the bottom of this bowl-shaped "pot-hole," the oxidized crust due to terrestrial rusting is over 1^{cm} thick. In general, however, the reddish-brown crust is only 1 or 2 millimeters in thickness. There is no evidence whatever of any surface flowing or melting of the iron. The remainder of the surface, including the reverse broad side, is quite covered by shallow depressions and low prominences. These lesser pits are 2 to

10^{cm} across and less than one-half as deep as their lateral radius. On the thick edge of the iron shown in the extreme left corner of fig. 1 is a pit about 2^{cm} broad and 2^{cm} deep, due to the aerial burning out or terrestrial oxidation of a surface nodule. The heavy oxidation in the large deep pit indicates that the meteorite did not fall recently.

After making casts, the mass was sawed at Philadelphia in a direction that would outline the deeper pits in cross section (fig. 4). The iron is exceptionally hard, due in part to the presence of occasional patches and thin leaves of schreibersite. On the etched surface these appear as long needles, one measuring 76^{mm} long and only 1 to 2^{mm} broad. This mineral also encases some of the nodules of troilite (fig. 5) which are frequent and range up to 3·5^{cm} in length; some at the surface are exposed on sawing. The largest so far uncovered (fig. 5) includes small rods and nodules of olivine about 2 to 3^{mm} across. The olivine appears to be opaque brownish-black, but under the microscope shows a yellowish-brown translucency and internal reflections. Another inclusion shows as dark capillary lines about 2^{cm} long, separating two parallel bands of kamacite. These minute fissure-like plates lie on edge, sometimes in parallel series and again without regular arrangement. When etched or broken, the iron is light gray. Polishing and etching with dilute nitric acid brings out the structure of a medium octahedrite, the kamacite bands mostly ranging between 0·5 and 1·5^{mm} broad. These are strongly outlined by the brighter taenite, the two making up the greater part of the mass. The predominance of kamacite bands and the relative scarcity of plessite groundmass tends to slightly confuse the otherwise very striking Widmanstätten figures. Two full size photographs of the same slab illustrate a common feature of meteoric irons. Fig. 5 shows the soft-toned kamacite and plessite which are prominent in most lights. Fig. 6 shows the same subject held at an oblique angle to catch the fullest reflections of the more brilliant taenite and schreibersite, thus obscuring, in part, the main constituents. The taenite is uniformly distributed throughout the mass. Its variation in fig. 6 is due to the etched surface not being perfectly level. Even the condensation of moisture from breathing on a polished surface momentarily develops well-marked figures of kamacite and plessite.

On comparing the Mount Edith iron with over two hundred meteorites, a close resemblance to the Bella Roca (Mexico) iron was observed. This likeness extends to all of the crystalline features, except the dark capillary lines before referred to. Bella Roca, however, according to Whitfield, contains 1·53 per cent less nickel and 1·98 per cent more iron than Mount Edith.

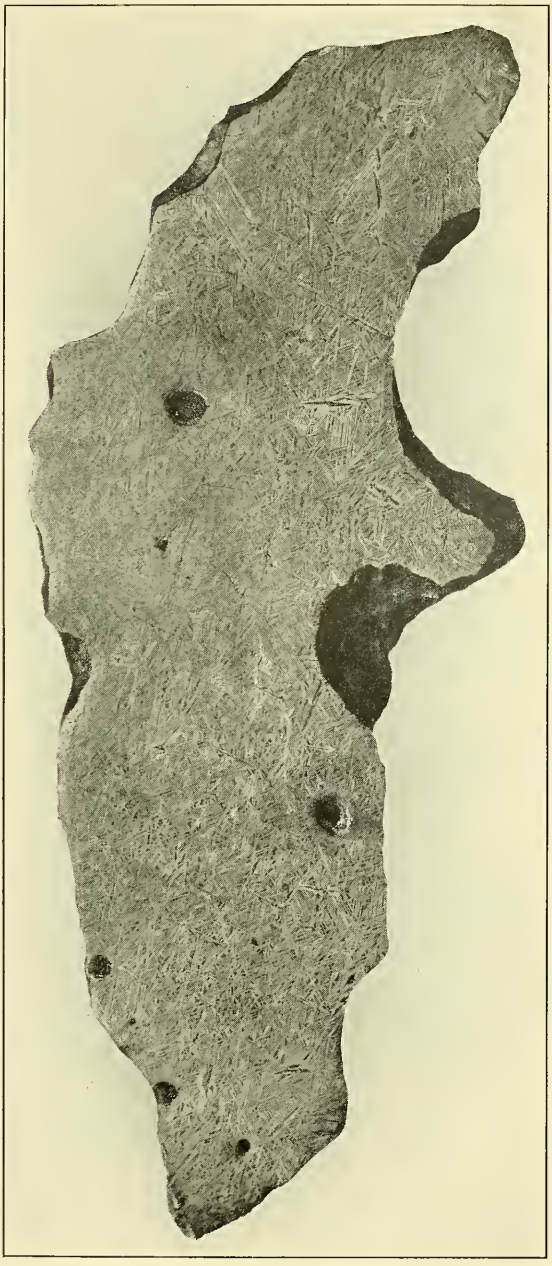


Fig. 4. Slice partly outlining deep pits. × 1/3 diameter.

Fig. 5. Showing kamacite and plessite. ×1 diameter.

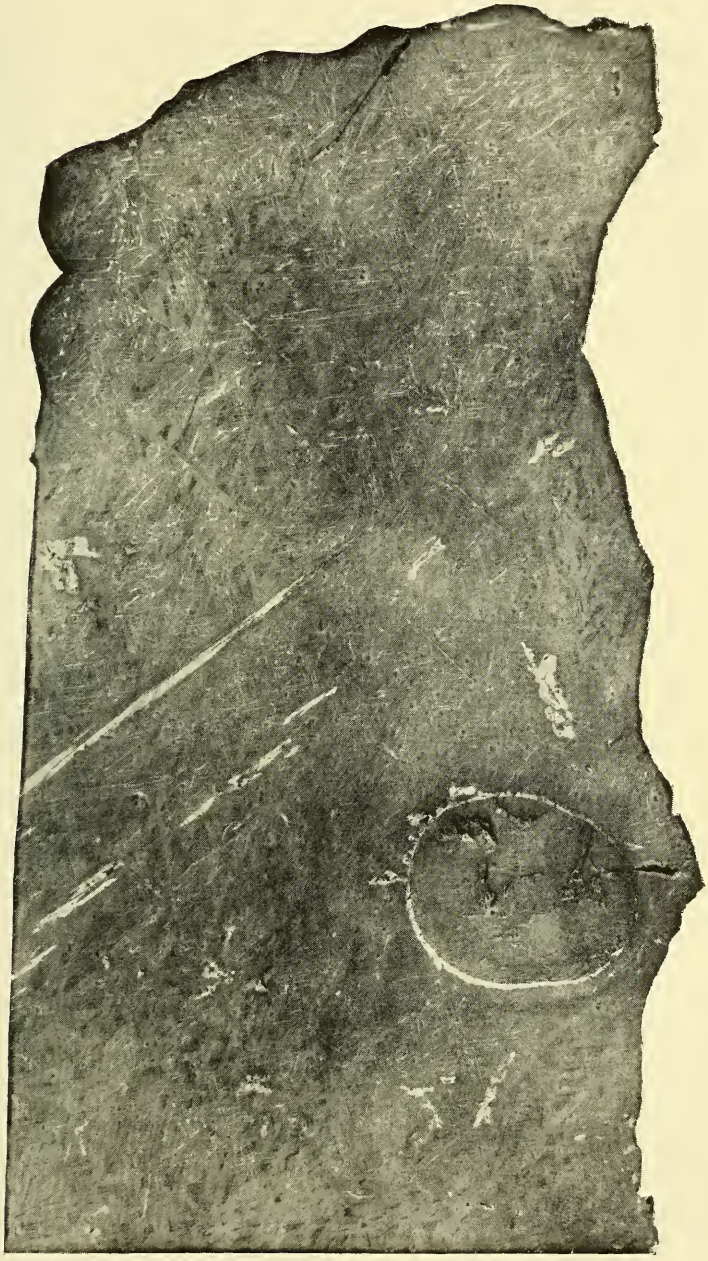


FIG. 6. Same slice at an oblique angle, reflecting taenite and schreibersite.

The nearest known geographical neighbor among irons is the Roebourne, found in 1894 two hundred miles southeast of the town of Roebourne and twenty miles from the Hammersley Range, 118° E., 22° 20′ S. This place is about 100 miles east of Mount Edith. Their points of difference are numerous and fully differentiate the two falls. While a medium octahedrite, Roebourne's figures are much dimmed by a schiller-like or flaky structure. It contains few troilite nodules and these are smaller than in Mount Edith. Roebourne contains little schreibersite and also carries 1·12 per cent less nickel and 1·414 per cent more iron than Mount Edith. The Ballinoo iron, found 300 miles to the south, has only 0·6 per cent less nickel and 0·4 per cent more iron than Mount Edith, but is totally unlike the latter in other respects. Ballinoo is one of the finest octahedrites, the figures being barely visible.

An analysis of the Mount Edith iron was made by Mr. J. Edward Whitfield of the firm of Booth, Garrett & Blair, Philadelphia. Their report follows:

Iron (direct)	89·500%
Nickel	9·450
Cobalt	0·625
Phosphorus	0·316
Carbon	0·017
Copper	0·013
Silicon	0·005
Sulphur	0·005
Manganese	none
	99·931

Included minerals were avoided as much as possible, and only clean drillings of the iron used for analysis. The material insoluble in hydrochloric acid amounts to 1·115 per cent. Considering the entire content of phosphorus as composing schreibersite, this would indicate that 2·10 per cent of this mineral was present in the iron. The specific gravity is 7·86.

Some six months previously, Mr. Edward I. Simpson, Chemist in the Laboratory of the Geological Survey of West Australia, reported the Mount Edith iron as containing 9·45 per cent nickel. This complete agreement with Mr. Whitfield's later analysis tends to show the uniform constitution of the mass throughout, as the sampling was done at different points. Such perfect concordance in the results of independent workers affords a pleasing commentary on the skill of both.

ART. XXXII.—*The Occurrence of Molybdenum in Rocks with special reference to those of Hawaii;* by J. B. FERGUSON.

SOME years ago, Dr. W. F. Hillebrand,* by a long series of determinations, showed that vanadium was most abundant in the less siliceous rocks, such as basalts, gabbros and diorites; while molybdenum seemed to be confined entirely to the more highly siliceous ones, the granites and rhyolites, not a trace of this element being found by him in the less siliceous rocks. It was, therefore, a matter of great surprise to find decidedly strong traces of molybdenum† in two basaltic lavas of Kilauea which were analyzed by me for Day and Shepherd. These analyses have been published in full.‡

On going over the list of rocks in which molybdenum was searched for by Hillebrand, it was noted that he had tested for it only in the more calcic and less sodic basalts and other less siliceous rocks, and that by some chance not a single test for this element had been made by him in nephelite-basanites and other distinctly sodic rocks in which he had looked for vanadium. As it is well-known that some of the rare elements are often found associated with one or other of the more common ones, zirconium with sodium, for example, or chromium with magnesium,§ it seemed possible that this might also be true of molybdenum, and that its presence in the basalts might have some connection with the decidedly sodic character of the Kilauean lavas. I therefore undertook the examination of some sodic, and especially nephelite-bearing igneous rocks. Dr. H. S. Washington kindly placed at my disposal a sufficient supply of the original material which had served for his analyses of several such rocks, together with a sample of a leucite trachyte exceptionally high in potash, on the chance that molybdenum might be found associated with this element. Dr. Hillebrand also was kind enough to provide me with some of the original material used by him for the analysis of a Hawaiian trachyte-obsidian described by Cross. As a matter of convenience, the complete analyses are collected in the following table:

* Hillebrand, W. F., Distribution and quantitative occurrence of vanadium and molybdenum in rocks in the United States. This Journal (4), vi, 209, 1896; Chem. News, lxxviii, 216, 1898; Bull. U. S. Geol. Survey, No. 167, p. 49, 1900.

† Dr. Hillebrand was kind enough to look at the blue coloration indicating molybdenum found by me, and to confirm my opinion that it was molybdenum.

‡ Day and Shepherd, Water and volcanic activity, Bull. Geol. Soc. Amer., xxiv, 573–606, pl. 17–27, 1913.

§ Washington, H. S., The distribution of the elements in igneous rocks, Trans. Am. Inst. Min. Eng., 1908, pp. 735.

	A	B	C	D	E	F	G	H
SiO_2	49·74	50·07	62·19	44·20	46·99	58·77	53·09	56·19
Al_2O_3	12·36	13·32	17·43	13·96	17·94	22·53	21·16	20·75
Fe_2O_3	1·64	1·92	1·65	3·19	2·56	1·54	1·89	1·71
FeO	10·08	9·28	2·64	8·41	7·56	1·04	2·04	2·19
MgO	8·83	8·01	0·40	8·03	3·22	0·19	0·32	1·14
CaO	10·88	10·64	0·86	9·79	7·85	0·74	3·30	3·53
Na_2O	2·45	2·16	8·28	3·66	6·35	9·62	6·86	2·86
K_2O	0·55	0·45	5·03	2·35	2·62	4·89	8·42	10·47
H_2O+	0·17	0·49	0·39	0·76	0·65	0·90	1·13	0·70
H_2O-	0·05	0·22	0·14	0·12	----	0·07	0·24	0·30
CO_2	none	none	0·02	none	----	----	0·82	none
TiO_2	2·49	2·70	0·37	4·10	2·92	0·31	0·11	0·65
ZrO_2	trace	none	0·04	----	----	0·11	0·04	----
MoO_3	0·01	trace	trace	none	none	none	none	none
P_2O_5	0·41	0·26	0·14	0·62	0·94	----	0·15	0·24
SO_3	trace	none	none	----	----	----	none	----
Cl	0·10	0·08	----	----	----	----	0·02	----
S	0·04	0·11	----	----	----	----	0·08	----
Cr_2O_3	0·04	0·05	trace	----	----	----	----	----
MnO	0·14	0·16	0·32	0·51	trace	trace	0·20	trace
NiO	0·05	0·04	----	0·14	----	----	----	----
BaO	trace	none	0·03	----	none	none	0·61	----
SrO	0·07	trace	none	----	----	----	----	----
	100·12*	99·96†	99·93	98·84	99·60	100·71	100·48	100·73

* Includes: Ce_2O_3 trace, V_2O_3 0·02, CuO none, Li_2O none.
† Includes: F none, Ce_2O_3 none, V_2O_3 none, CuO none, Li_2O none.

A. Basalt (camptonose, III.5.3.4). Halemaumau, Kilauea.
J. B. Ferguson, analyst. Day and Shepherd, Bull. Geol. Soc. Am., xxiv, p. 586, 1913.

B. Basalt (auvergnose, III.5.4.5). Floor of crater, Kilauea.
J. B. Ferguson, analyst. Day and Shepherd, ibid.

C. Trachyte-obsidian (umptekose, II.5.1.4). PuuWaaWaa, Hawaii.
W. F. Hillebrand, analyst. W. Cross, J. Geol., xii, 514, 1904.

D. Nephelite basanite (limbargose, III.6.3.4). Cruz Cat, Olot, Spain.
H. S. Washington, analyst, this Journal, xxiv, 239, 1907.

E. Essexite (essexose, II.6.2.4). Salem Neck, Essex County, Massachusetts.
H. S. Washington, analyst, J. Geol., vii, 57, 1899.

F. Nephelite syenite (miaskose, I.6.1.4). Salem Neck, Essex County, Mass.
H. S. Washington, analyst. J. Geol., vi, 803, 1898.

G. Nephelite syenite (beemerose, I.6.1.3). Magnet Cove, Arkansas.
H. S. Washington, analyst, J. Geol., ix. 611, 1901.

H. Leucite trachyte (vulsinose, I.5.2.2). Lake Vico, near Viterbo, Italy.
H. S. Washington, analyst, Carnegie Publication No. 57, p. 36, 1906.

As full petrographic descriptions of the two Kilauea basalts have not previously been published, it will not be out of place to insert them here. Dr. Whitman Cross, who has made a

special study of the Hawaiian lavas, kindly undertook the examination of the slides for me, and his notes on them are given below:*

A. Lava dipped from the Pit of Halemaumau.

"Black, porous, few white and yellowish mineral grains. Luster brilliant vitreous. Pores round with glossy walls."

"Microscope: Glass predominant, yellow-brown, very fresh. Has few minute bubbles; some pores have narrow zones of ferritic glass about them; some are in pure glass. Fuzzy streaks or trains, of ferritic substances, more or less curved, connect some pores, Labradorite, augite and olivine are all prominent in distinct crystals. Augite and labradorite tend to form groups. Olivine occurs isolated and some are more or less markedly skeleton crystals. All are quite fresh. Magnetite is very rare and is mostly included in silicate grains."

B. Lava from Kilauea floor.

"A dull black finely porous lava with megascopically abundant feldspar and augite, and less olivine."

"Microscope: There is much labradorite and augite with tendency to form groups of several grains of each. Olivine is less abundant, but occurs in larger isolated crystals and is very fresh. Main mass of rock is greatly obscured by ferritic material, but there is rude development of plumose bundles or radiate aggregates of silicates. These forms consist of labradorite needles with attached augite grains, the ferritic substance obscuring their character. Both rocks are quite normal basalts of the Kilauea type."

The molybdenum was determined in all cases on 5 gram samples, the procedure† advocated by Hillebrand being closely followed. With reference to the occurrence of molybdenum in the Hawaii lavas, it must be remarked that in the two basalts, A and B, the molybdenum tests were made in duplicate, and decidedly strong traces were found in each case. As especial precautions were taken in the duplicates to avoid contamination, the result can not be attributed to accidental impurity. As the amount of the trachyte obsidian was limited, only one test was made. The amount found was rather less than in A or B. The amount in A exceeded that in B, and an attempt to weigh it gave the percentage as approximately 0·01. The negative tests obtained in the other

* Attention may be called to the fact that the short description of these lavas by Merwin (Day and Shepherd, Bull. Geol. Soc. Amer., xxiv, 573–606, 1913) was made on the powders, and not on thin sections, which may serve to explain apparent discrepancies between the two descriptions.

† Bull. U. S. Geol. Survey, No. 422, p. 150, 1910.

rocks, using the same reagents as with the Hawaiian rocks, speak for the purity of the reagents employed.

From these results, combined with those of Hillebrand, it would therefore appear that while molybdenum favors the more siliceous rocks and is generally rare or absent in the less siliceous or more femic ones, yet in certain regions it may be present even in the latter. The evidence at hand, so far as it goes, also indicates that the presence of molybdenum is not correlated with high soda or potash content, at least in the petrographic provinces the rocks of which were examined. Its presence in detectable amounts would seem to be influenced by regional characters rather than by general chemical ones, except for the pronounced tendency toward association with highly siliceous rocks first noted by Hillebrand. The unexpected results obtained, however, indicate the advisability of occasionally searching for molybdenum, which is readily detectable if present, even though the analytical processes are somewhat tedious.

Geophysical Laboratory,
Carnegie Institution of Washington,
March, 1914.

Art. XXXIII.—*Fruits of a Date Palm in the Tertiary Deposits of Eastern Texas;* by Edward W. Berry.

So much study and experiment have been devoted to making practical the cultivation of the date palm in the hot arid southwest* that the recent discovery of the fossil fruits of a species of date palm in the Tertiary of eastern Texas is of exceptional interest.

The considerable range of species of Phoenix-like palms in the south European Tertiary has led to the expectation of their discovery in our more tropical southern Tertiaries when these should have been thoroughly explored, just as the Bread-fruit, Cinnamon tree and Nipa palm have been found; nevertheless, the actual finding of proof of the former existence of a date palm in the Western Hemisphere is one of the more spectacular incidents of the paleobotanists' work, since it is likely to attract more attention from botanists and geologists engrossed in their own special lines of study than a tome of admirable descriptive paleobotanical work. In order that the presence of the date palm in the American Tertiary may not remain unknown until my monographic studies of our southern Tertiary floras are published, which will be a number of years hence, I am prompted to publish the present brief note.

In the course of my studies for the U. S. Geological Survey and under the supervision of Dr. T. Wayland Vaughan, I have had the good fortune to receive collections of fossil plants from eastern Texas made under the direction of the veteran geologist, E. T. Dumble, now associated with the Southern Pacific Company. The material on which the following note is based was collected by Chas. Laurence Baker in Trinity county, Texas, and while not abundant contains both large and small seeds and a cast of the entire fruit of a new species of Phoenix-like palm which may with propriety be referred to Brongniart's genus Phoenicites. I propose to call this species *Phoenicites occidentalis.* It may be described as follows: Fruit, as preserved in a coarse gray sandstone, an oblate spheroid about 4^{cm} in length by $1{\cdot}5^{cm}$ in breadth. The surface is longitudinally wrinkled, due possibly to desiccation before preservation, which may also make the dimensions as given probably under what they were in life. The flesh was relatively thin compared with that of the cultivated date and must have been of considerable consistency and fibrous rather than of the soft and almost fluid character of some of the modern varieties of the latter. The seed was relatively large—in the above mentioned specimen it is rounded at both ends, about 3^{cm} in length,

*Swingle, Bull. 53, Bureau of Plant Industry, Washington, 1904.

nearly circular in transverse section and about 1[cm] in diameter. A smaller specimen shows a length of about 2·5[cm] and a diameter of 8[mm]. The larger of these seeds shows the central hilum, the deep longitudinal sinus on the opposite side, the transverse lamellated structure exactly comparable to that of a modern date seed and the finely corrugated surface coat identical with that of a dried seed of a modern date. The smaller specimen, while not so perfect, shows the general form and sinus and the lamellated structure. There can be no doubt

Fig. 1.

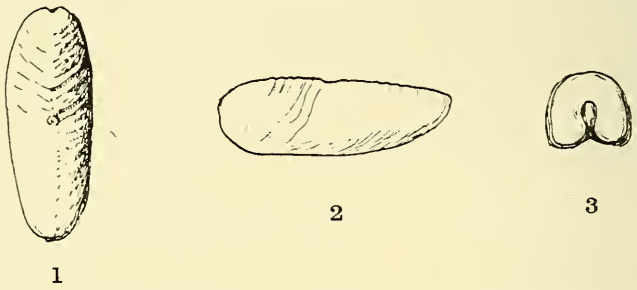


Fig. 1. Top side and end view of type of *Phoenicites occidentalis* (nat. size).

that these remains are those of a Phoenix-like fruit and it is confidently expected that the foliage will eventually be discovered, in fact some of the fragments of palm-rays found at this and other horizons in our southern Tertiary may represent this foliage. Petrified wood of several species of palms is exceedingly abundant in these beds, and while the study of palm woods has not progressed to a point where one can speak with certainty of the generic relations of the petrified woods, it is significant that wood of several different species occurs at this horizon.

While the geologic record is confessedly incomplete, a number of fossil species of Phoenix-like forms have been described, in fact there are more fossil than recent species. These are usually referred to the genus Phoenicites of Brongniart as in the present case, although some students refer them directly to the genus Phoenix of Linné. The previous fossil occurrences are all European and are based on leaves and inflorescence. In 1886 Conwentz* described a flower preserved in perfection in the Baltic amber and the staminate inflorescence of another species is associated with splendid leaves in the Eocene of the Paris basin.† The oldest known form comes from the middle or upper Eocene of the Paris basin, while in

* Conwentz, Fl. Bernsteins, vol. ii, p. 8, pl. 1, figs. 6-9, 1886.
† Saporta, Essai pl. foss arkoses de Brives, p. 25, pl. 1, 1878.

the succeeding Oligocene period the remains of date palms are abundant in Germany, Bohemia, and especially in northern Italy. They are present in the early Miocene of France, Switzerland, and Croatia. A species is recorded from the west coast of the Adriatic in Pliocene times and the presence of a well marked form which Drude calls *Phoenix dactylifera fossilis*, since it is so much like the existing date, is found in the Pleistocene deposits of the volcanic island of Santorin in the Ægean Sea. The latter occurrence indicates that the date

Fig. 2.

Fig. 2. Sketch map showing the area within which species of Phoenix occur and the fossil occurrences of Phoenicites (stars).

palm was endemic in at least a part of southern Europe until comparatively recent geologic times.

The cultivated date belongs to a group of about a dozen existing species referred to the genus Phoenix, all of which are confined to northern Africa and southern Asia, the bulk of the species being indigenous in the Indian region. Two of the African species, *spinosa* and *reclinata*, are small shrubby forms with small fruits, found along the coasts of Senegambia, Sierra Leone and Natal. The true date in countless varieties has existed since prehistoric times in the hot dry zone extending from Senegal eastward to the basin of the Indus. Dates are so readily transported by primitive races and germinate so readily from the seed that it is difficult to establish the original distribution of the species. Egyptian monuments contain

fruits and drawings of the date and Assyrian inscriptions show that it grew in abundance in the region lying between the Euphrates and the Nile. Herodotus mentions the uses of the wood in Babylon and somewhat later Strabo indicates its abundance in Arabia. There is no historic evidence of the existence of the date palm west of Egypt in the oases of the Sahara, but Pliny mentions its occurrence in the Canaries. If these facts were wanting, a philological study of the names applied to the date would indicate that the most ancient peoples of these regions with a written language, as for example the Egyptians, found the date indigenous in their country. The Greek name *Phoenix* refers simply to the fact that the Phœnicians were possessors of the tree and traded in its fruits, while the specific name of the species *dactylifera* and the vernacular name *date* are both, according to Ritter, derivations of the Hebrew *dachel*.

The commercial date does not perfect its fruit except in incredibly hot climates where clouds are not common and where all forms of atmospheric humidity are very low, in fact no amount of heat or degree of dryness of the air is injurious provided the roots have access to a sufficient supply of moisture. There is an old Arab proverb which says of the date, "its feet shall be in a stream of water and its head in the furnace of heaven." While the great caravan routes that traverse the deserts of northern Africa and southwestern Asia are intimately associated with date culture and while the finest varieties grow in the oases and sunken gardens of the Sahara, a consideration of the ecology of the date and of the other existing species of Phoenix, at least two of which are coastal types, indicates that the geologic ancestors were not necessarily desert types but inhabitants of coasts and stream banks where the water-table approached near enough to the surface to become available for their root system. When corroborated by the associated forms of vegetation they may indicate hot climates with a scanty rainfall as they probably do in east Texas, and it seems certain that temperatures could not have gone below 18° C. without being fatal.

Phoenicites occidentalis comes from a cut on the International and Great Northern Railroad in southern Trinity county, where a spur to the Government Lock leaves the main line. The outcrop is referred to the Catahoula formation, which in this region is of late Eocene or early Oligocene age. The type is shown in the accompanying text figures (fig. 1), while the sketch map (fig. 2) shows in a generalized way the area of distribution of the existing species of Phoenix and the fossil occurrences of Phoenicites.

Johns Hopkins University, Baltimore, Md.

ART. XXXIV.—*The Separation of Titanium from Iron, Aluminum, and Phosphoric Acid with the Aid of the Ammonium Salt of Nitrosophenylhydroxylamine ("Cupferron"); by* WILLIAM M. THORNTON, JR.

[Contributions from the Kent Chemical Laboratory of Yale Univ.—cclvii.]

IT has been shown by the author* that titanium can be quantitatively precipitated in solutions moderately acidified with sulphuric acid and containing also tartaric acid by the ammonium salt of nitrosophenylhydroxylamine ("cupferron"). Making use of this fact, an indirect separation of titanium from iron has been accomplished. In this method, after precipitating the iron as ferrous sulphide by ammonium sulphide in the presence of ammonium tartrate and filtering from the aforesaid ferrous sulphide, the iron free filtrate is acidified with sulphuric acid, the hydrogen sulphide boiled out, and the titanium precipitated in the cold by the "cupferron" reagent. The yellow precipitate thus produced is collected and ignited to titanic oxide. At the close of the article it was stated that it would seem that there should be no great difficulty attending the separation of titanium from iron, aluminum, and phosphoric acid. Experiments with a view to accomplishing these separations have been fraught with very interesting and very gratifying results.

Although Schröder† has made the statement that titanium and zirconium could be quantitatively precipitated by the "cupferron" reagent, no experimental data have appeared on the subject until Bellucci and Grassi‡ showed that titanium could be quantitatively thrown down by the reagent and that a clean separation of titanium from aluminum could be brought about by a single precipitation in acid solution. Their results leave little to be desired for accuracy. But it is indeed surprising that these writers do not give in any but the most indefinite terms the acid concentration or the absolute volume of the solutions in which the titanium was precipitated. They say that the solution should be notably but not excessively acid with either sulphuric or hydrochloric acid. Again, under the separation of titanium from aluminum they say that the same acidity was used for the separation as for the precipitation of titanium alone, and that the precipitate was washed first by decantation and then on the filter with very dilute hydrochloric acid. Just how large a quantity of either of the above two acids can be employed and the precipitation of the titanium still be complete has not yet been determined. But the author's experiments have clearly demonstrated that if the concentra-

* This Journal, xxxvii, p. 173, 1914.
† Zeitschr. anorg. Chem., lxxii, 89, 1911.
‡ Gazzetta Chimica Italiana, Anno xliii, Parte I, 570, 1913.

tion of sulphuric acid be too small, the aluminum is carried down with the titanium in considerable measure.

For these experiments two standard solutions of titanic sulphate were employed. These were made by acting on specially prepared potassium fluotitanate with concentrated sulphuric acid until all the hydrofluoric acid had been displaced, diluting and making up to known volume. The first solution was standardized by taking two weighed portions of 25^{cm^3} each and precipitating the titanium by hydrolysis of the acetate upon boiling in the manner previously described by the author.* Duplicate determinations gave the following results :

Titanic sulphate soln.	Titanic oxide	
(*a*) 25^{cm^3} =◯= 27·308 grm.	0·1427 grm.	0·5226%
(*b*) 25^{cm^3} =◯= 27·319 grm.	0·1428 grm.	0·5227%

Since these two results agreed so closely, the value obtained in (b) was arbitarily taken as correct. The second solution was standardized by taking weighed portions of 25^{cm^3} and 24^{cm^3} respectively and determining the titanium in one (a) by the acetate method and in the other (b) by the "cupferron" method of Bellucci and Grassi.† Two determinations gave the following results :

Titanic sulphate soln.	Titanic oxide	
(*a*) 25^{cm^3} =◯= 27·814 grm.	0·1066 grm.	0·3822%
(*b*) 24^{cm^3} =◯= 26·667 grm.	0·1022 grm.	0·3822%

Since these two determinations agreed exactly, the value here obtained was taken as correct.

The first series of experiments were carried out with a view to obtaining favorable conditions for the separation of titanium from aluminum. Known quantities of aluminum were added by weighing off dry ammonium aluminum sulphate, which had been purified by two recrystallizations. To the solution containing the titanium and aluminum and a weighed amount of tartaric acid (except in the case of experiments (1) and (2) which were made in the absence of tartaric acid) redistilled ammonium hydroxide was added until the solution became neutral to litmus paper. A definite volume of sulphuric acid (made by diluting one volume of acid of sp. g. = 1·84 with an equal volume of water) was then added and the solution made up to the volume designated in the last column of Table I. Twenty cubic centimeters of a 6 per cent "cupferron" solution was then added and the beaker set aside for the precipitate to settle. The time of standing does not appear to matter a

* Loc. cit., p. 174. † Loc. cit.

great deal. Two hours was found to be satisfactory; but no doubt a shorter time would suffice, and in a few cases the precipitate was allowed to stand about twelve hours with no harmful consequences. The precipitate was filtered on paper with the aid of very gentle suction, washed twenty times with water containing 20^{cm^3} of hydrochloric acid of sp. g.=1·20 per litre, placed in a tared platinum crucible and dried at 110° C., ignited at first very carefully with the cover on, then with the crucible inclined and open until all the carbon had been consumed, and finally brought to constant weight over the Meker burner. From experiments (1) and (2) it is evident that if the concentration of free sulphuric acid be too small, very serious errors are made in the direction of gain of weight on the titanium. Since, after the separation of the iron, the filtrate from the ferrous sulphide contains already tartaric acid, it was considered advisable at this point to learn the effect of tartaric acid on the next operation in the analysis, viz., the separation of titanium from aluminum. Since the conditions in experiments (3) and (4) are the same as those in experiments (1) and (2) respectively, excepting the presence of tartaric acid, it is obvious that if this acid be present in the solution, the concentration of free sulphuric acid necessary to bring about a clean separation can be greatly diminished. In experiments (5) and (6) it will be noticed that with small increments in acidity the error is very slightly lowered. If the original solution for the analysis occupy a volume of 100^{cm^3} the author has found that in his experience the filtrate and washings from the ferrous sulphide will occupy a volume of about 350^{cm^3}. An absolute volume of 400^{cm^3} was therefore chosen as a convenient one in which to make the precipitation of titanium. Accordingly experiments (7) and (8) were performed with the object of learning the quantities of sulphuric acid and of tartaric acid necessary to effect a good separation in the above given absolute volume. In these two experiments the concentration of sulphuric acid was the same as in experiments (4) and the tartaric acid increased somewhat over the amount previously used. Since the results of experiments (7) and (8) were satisfactory it was not thought necessary to carry the series further.

The second series of experiments was begun with the object of determining how great a concentration of sulphuric acid could be employed in the presence of tartaric acid without any resultant loss of titanium. The mode of procedure was the same as in the separation of titanium from aluminum except that in experiment (9) the precipitate was washed with water and in experiments (11) and (12) with hydrochloric acid (made by diluting 100^{cm^3} of acid of sp. g.=1·20 to one liter). Since in experiment (12) the concentration of sulphuric acid was

Table I.

The Separation of Titanium from Aluminum.

No.	TiO_2 taken grm.	Al_2O_3 taken grm.	TiO_2 found grm.	Error grm.	H_2SO_4 (1:1) cm^3	Tartaric acid grm.	Volume of soln. cm^3
1	0·1066	0·1127	0·1179	+0·0113	5	--	200
2	0·1066	0·1127	0·1094	+0·0028	10	--	200
3	0·05715	0·1127	0·0590	+0·0018	5	1·2	200
4	0·0572	0·1127	0·0577	+0·0005	10	1·2	200
5	0·0575	0·1127	0·0579	+0·0004	15	1·2	200
6	0·0573	0·1127	0·0575	+0·0002	20	1·2	200
7	0·1067	0·1127	0·1072	+0·0005	20	1·5	400
8	0·1068	0·1127	0·1070	+0·0002	20	1·5	400

twice as great and the quantity of tartaric acid greater by half a gramme also than were found necessary to insure a clean separation of titanium from aluminum, and since the error on titanium was one of gain, it appeared that there was little to be profited by carrying the series further.

Table II.

No.	TiO_2 taken grm	TiO_2 found grm.	Error grm.	H_2SO_4 (1:1) cm^3	Tartaric acid grm.	Volume of soln. cm^3
9	0·1428	0·1429	+0·0001	5	0·5	200
10	0·1066	0·1069	+0·0003	20	1·5	400
11	0·1064	0·1067	+0·0003	30	2·0	400
12	0·1064	0·1066	+0·0002	40	2·0	400

Fresenius* has succeeded in obtaining a quantitative separation of iron from phosphoric acid in a solution acid with hydrochloric acid by means of the "cupferron" reagent. Mindful of this, it occurred to the author that in a similar way it might be possible to separate titanium from phosphoric acid. The third series of experiments was, therefore, undertaken with this object in view. Approximately known quantities of phosphoric acid were added by weighing off dry portions of Baker's analyzed disodium hydrogen phosphate. The conditions of experimentation were like those described above for the titanium aluminum separation. Table III contains the

Table III.

The Separation of Titanium from Phosphoric Acid.

No.	TiO_2 taken grm.	P_2O_5 taken grm.	TiO_2 found grm.	Error grm.	H_2SO_4 (1:1) cm^3	Tartaric acid grm.	Volume of soln. cm^3
13	0·1064	0·0711	+0·1071	+0·0007	20	1·5	400
14	0·1066	0·0710	+0·1067	+0·0001	25	1·5	400

*Zeitschr. anal. Chem., 1, 35, 1911.

results of two experiments. Since experiment (14) was entirely satisfactory, it was deemed unnecessary to extend the series further.

It only remained to connect the three separations in order to complete the method of analysis. In experiments (15), (16), (17), and (18) known quantities of iron were introduced by adding weighed portions of Kahlbaum's ferrous ammonium sulphate. In experiments (19) and (20), a standard solution of ferric ammonium sulphate was used. In one portion (a) of 25^{cm^3} the iron was determined by titration with potassium permanganate after reduction of the iron by zinc—the potassium permanganate having been previously standardized against sodium oxalate. In another portion (b) of 25^{cm^3} the iron was determined by precipitation with ammonium hydroxide and ignition of the ferric hydroxide to ferric oxide. Parallel determinations gave the following results:

Ferric sulphate soln.	Ferric oxide
(*a*) 25^{cm^3}	0·2267 grm.
(*b*) 25^{cm^3}	0·2269 grm.

The value obtained in (a) was taken as correct. Throughout the fourth series of experiments a standardized solution of phosphoric acid was used. This was prepared by diluting Baker and Adamson's 85 per cent acid. In two portions of 25^{cm^3} each the phosphoric acid was precipitated as ammonium magnesium phosphate. Duplicate determinations gave the following results:

Phosphoric acid soln.	Phosphorus pentoxide
(*a*) 25^{cm^3}	0·15256 grm.
(*b*) 25^{cm^3}	0·1528 grm.

The mean of these two values was taken as correct. Since the phosphoric acid present in titaniferous rocks is generally small in amount relative to the other constituents, it was thought best to dilute this solution ten fold by volume. The resulting solution, therefore, contained in 25^{cm^3} 0·0153 grm. of phosphorus pentoxide. In Table IV are set forth the results of six experiments in which the whole analysis was performed.

For the benefit of the practical analyst the technique of the entire analysis is here connectedly given. To the solution, which should not be much greater than 100^{cm^3} in bulk, at least four times the aggregate weight of the four oxides to be held by it in solution of tartaric acid is added. To facilitate the reduction of the iron the solution is made neutral with ammonium hydroxide and acid again with 2^{cm^3} of sulphuric acid (1:1). Hydrogen sulphide is then introduced until

TABLE IV.

The Separation of Titanium from Iron, Aluminum, and Phosphoric Acid.

No.	TiO_2 taken grm.	Fe_2O_3 taken grm.	Al_2O_3 taken grm.	P_2O_5 taken grm.	TiO_2 found grm.	Error grm.	H_2SO_3 (1:1) cm^3	Tartaric acid grm.	Volume of soln. cm^3
15	0·1065	0·2036	0·1127	0·0154	0·1070	+0·0005	30	2	400
16	0·1066	0·2036	0·1127	0·0151	0·1068	+0·0002	30	2	400
17	0·1065	0·1018	0·1127	0·0153	0·1067	+0·0002	40	2	400
18	0·1067	0·1018	0·1127	0·0153	0·1069	+0·0002	40	2	400
19	0·1066	0·2267	0·2254	0·0153	0·1069	+0·0003	40	2·5	400
20	0·1066	0·2267	0·2254	0·0153	0·1073	+0·0007	40	2·5	400

the solution has become colorless. Unless the iron is thus reduced before precipitation, titanium will be in part thrown down also.* Ammonium hydroxide is then added in decided excess and more hydrogen sulphide introduced until the iron has been completely thrown out as ferrous sulphide—leaving the solution, however, alkaline to test-paper. The ferrous sulphide is filtered off and washed with very dilute colorless ammonium sulphide about ten times. To the filtrate is then added 40^{cm^3} of sulphuric acid (1:1) and the hydrogen sulphide thus liberated boiled out. After cooling to room temperature the solution is made up with water to 400^{cm^3} and a 6 per cent solution of "cupferron" added slowly with constant stirring. The beaker is then set aside for the precipitate to settle. After the precipitate has subsided the supernatant liquid is tested by adding a few drops of the reagent. The formation of a white precipitate of nitrosophenylhydroxylamine indicates that the reagent had been added in excess; whereas the formation of a yellow turbidity shows the precipitation to be incomplete. It is well also to test the filtrate. The precipitate is collected on a paper filter—using gentle suction, and washed twenty times with hydrochloric acid (made by diluting 100^{cm^3} of acid of sp. g.=1·20 to one liter). After having been sucked free of drainage water at the pump, the precipitate and filter are placed in a tared platinum crucible† and dried at 110° C. With the crucible not quite covered by the lid the ignition is begun with a very small flame. After the first violent gush of smoke the heat is raised a little, when the destructive distillation will proceed quietly. After burning away the carbon, the residual titanic oxide is brought to constant weight over the Meker burner. In the paper‡ previous to this, where the separation of titanium and iron only was under consideration, the author has directed that the acidified filtrate from the ferrous sulphide be partially neutralized with ammonium

* Cathrein, A., Zeitschr. Kryst., vi, 243, 1882; vii, 250, 1883.

† A quartz crucible is also satisfactory for the ignition.

‡ Loc. cit.

hydroxide. It should be here noted that in the light of the further experiments recorded above, this is, of course, entirely unnecessary.

On account of the small amounts of platinum that find their way into the solutions during mineral and rock analysis, being derived from the platinum vessels by the attack of certain fluxes (such as alkali pyrosulphate or a mixture of sodium carbonate and potassium nitrate) on prolonged fusion or by the action of certain oxidizing agents (such as sodium manganate, sodium chromate, etc.) on hydrochloric acid, and since Chatard* in his modifications of the method of Gooch† has recommended the removal of platinum from the solution by hydrogen sulphide prior to the final precipitation of the titanium; it was thought advisable to find out whether or not the titanic derivative of nitrosophenylhydroxylamine carried down appreciable masses of platinum. Chlorplatinic acid was dissolved in water so as to make a solution containing approximately one mgrm. of platinum in every cubic centimeter. Table V contains the results of two experiments, which show that the precipitate has little, if any, tendency to include platinum.

Table V.

The Separation of Titanium from Platinum.

No.	TiO_2 taken grm.	Pt. taken (approx.) grm.	TiO_2 found grm.	Error grm.	H_2SO_4 (1:1) cm^3	Volume of soln. cm^3
21	0·1067	0·0100	0·1071	+0·0004	40	400
22	0·1067	0·0100	0·1066	−0·0001	40	400

The success of this analytical research has depended on three very fortunate phenomena. First: the precipitate of the titanium by the "cupferron" reagent is quantitative in the presence of tartaric acid—a fact which obviates the necessity of oxidizing the tartaric acid. Second: the separation of titanium from aluminum is facilitated by tartaric acid to the extent of greatly diminishing the concentration of free mineral acid necessary. Third: a clean separation of titanium from phosphoric acid can be accomplished under the same conditions as the separation of titanium from aluminum, which seems to the author remarkable when one considers the insolubility of the basic phosphate of titanium even in decidedly acid media and the difficulties in handling these two substances in solution. The following points of merit are claimed for the method. The whole analysis is accomplished by two precipitations—the titanium being separated from both aluminum and phosphoric

* Am. Chem. Jour., xiii, 109, 1891.

† Proc. Am. Acad. Arts and Sci., n.s., xii, 435, 1885. See also Hillebrand, Bull. U. S. G. S., 422, 97, 107, 1910.

acid in one operation—so that the time required for the estimation of titanium in the presence of iron, aluminum, and phosphoric acid is no greater than the time required for the estimation of titanium when associated with iron only; since after filtering off the ferrous sulphide the technique is exactly the same in either case. The precipitate comes down immemediately and quantitatively in the cold in flocculent and readily filterable condition, has little tendency to include alkalies, and after drying can be easily converted to titanic oxide of a high degree of purity. The entire procedure is so simple that the attainment of good results by the analyst is almost inevitable.

In order that analytical chemists may have at hand directions for the preparation of the ammonium salt of nitrosophenylhydroxylamine* an abstract of Baudisch's† instructions for its synthesis is here appended.

Sixty grms. of nitrobenzene, 1000$^{cm^3}$ of water, and 30 grms. of ammonium chloride are stirred rapidly to an emulsion. Eighty grms. of zinc dust is added in small portions to the stirred emulsion by means of a knife blade; the temperature being kept between 16° and 18° C. by the occasional addition of a little shaved ice, until there is no longer an odor of nitrobenzene and the precipitate is gray. The reduction is accomplished in about one-half hour. The solution is filtered from the zinc hydroxide, which is washed a few times with iced water. The filtrate, cooled to nearly 0° C., is saturated with sodium chloride. Whereupon phenylhydroxylamine crystallizes out in white needles. These are collected on a perforated funnel and dried by being pressed between filter papers. The yield is generally 70–85 per cent of the theoretical. This body is a skin poison and if spattered on the hands or face should be at once washed off with water and then with alcohol. The crystals are dissolved in 300–500$^{cm^3}$ of commercial ether and the solution filtered from any residual sodium chloride. The ethereal solution, cooled to 0° C., is saturated with dry ammonia gas. While still at 0° C., the calculated weight of fresh amyl nitrite (one molecule to every molecule of nitrobenzene) is added. The vessel is immediately filled with glistening white crystals of the ammonium salt of nitrosophenylhydroxylamine.‡ After filtration and washing with ether, the crystals are dried by filter paper, and kept in a closely stoppered bottle in which is also placed a small lump of ammonium carbonate.

February 18, 1914.

*Kahlbaum's salt can be purchased from Messrs. Eimer & Amend, New York.

†Chem. Zeitung., xxxv, 223, 1911.

‡$C_6H_5NO.NONH_4$.

Art. XXXV.—*New Features in the Geology of Northwestern Spitzbergen;* by Olaf Holtedahl.

For its high latitude, Spitzbergen has long been a singularly well-studied country geologically. Forty years ago the well-known Swedish geologist and explorer, A. E. Nordenskiöld, was able to describe no less than nine formations known from the islands, and since that time a great number of geologists, and above all Nathorst, De Geer and others of Sweden, have added much to our knowledge. Nevertheless, the more detailed investigations have been carried on chiefly in but one part of Spitzbergen, viz., the central part of West Spitzbergen, the region of the Ice Fjord and Bell Sound.

During the past four years, Norwegian expeditions have worked in the previously very little known northwestern corner of West Spitzbergen and in the Prince Charles Foreland. The expeditions of 1909-1910 were in charge of Captain G. Isachsen, those of 1911-1912 in charge of Captain A. Staxrud and cand. real. A. Hoel. As geologists Hoel has worked each summer, Holtedahl during the three summers of 1909–11. During these four summers we have mapped geologically almost the whole northwest corner and have determined the chief features of the geological structure and the essential stratigraphy of the area studied. It is the purpose of this paper to describe some of the results attained.

Nathorst, in his valuable book of 1910, "Beiträge zur Geologie der Bären-Insel, Spitzbergens und des König-Karl-Landes,"* has recognized the following systems :

Quaternary
Tertiary
Jurassic with Neocomian
Triassic
Permian
Carboniferous
Devonian
Heclahook
Archean

Of younger igneous rocks were known sheets and dykes of diabases, probably of Cretaceous age.

One of our important results is the determination that there is no Archean at all in the northwest corner of Spitzbergen, as was previously held to be the case. As early as 1909, during a sledge trip across the country from Cross Bay to Red

* Bull. Geol. Inst. Upsala, vol. x.

Fig. 1.

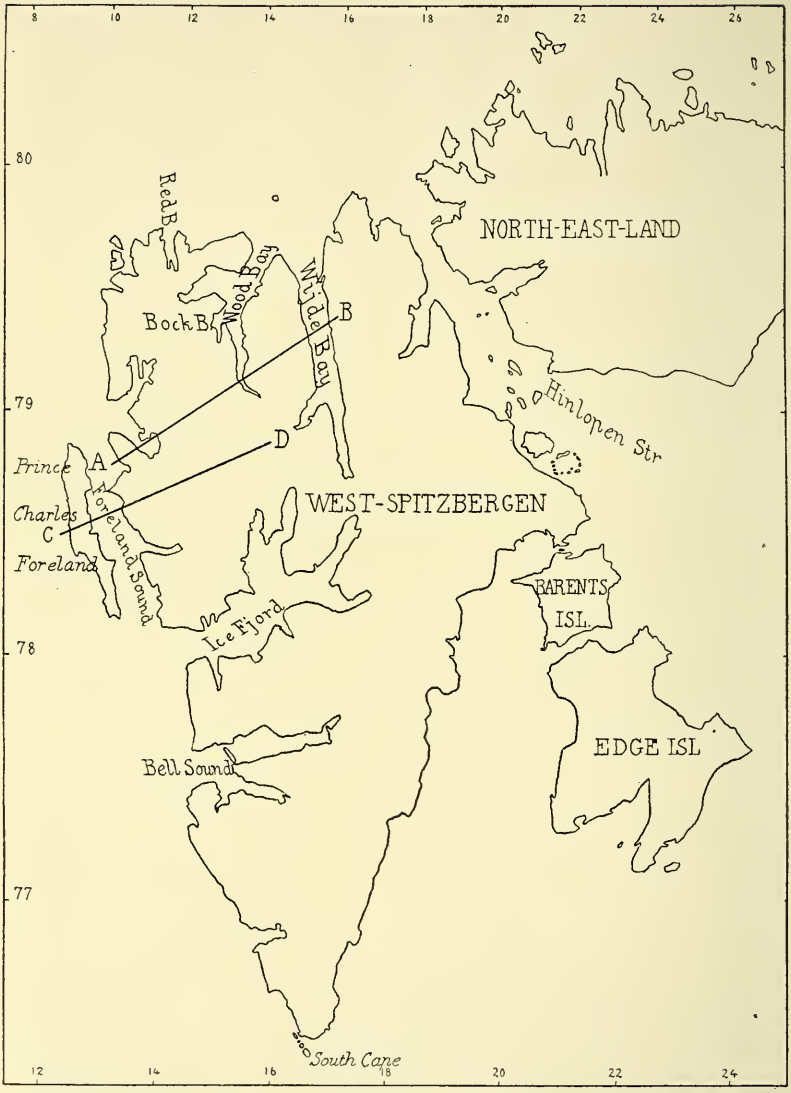


Fig. 1. Outline map of the Spitzbergen Archipelago. The two lines in the northwestern corner show the location of the sections, page 419.

Fig. 2.

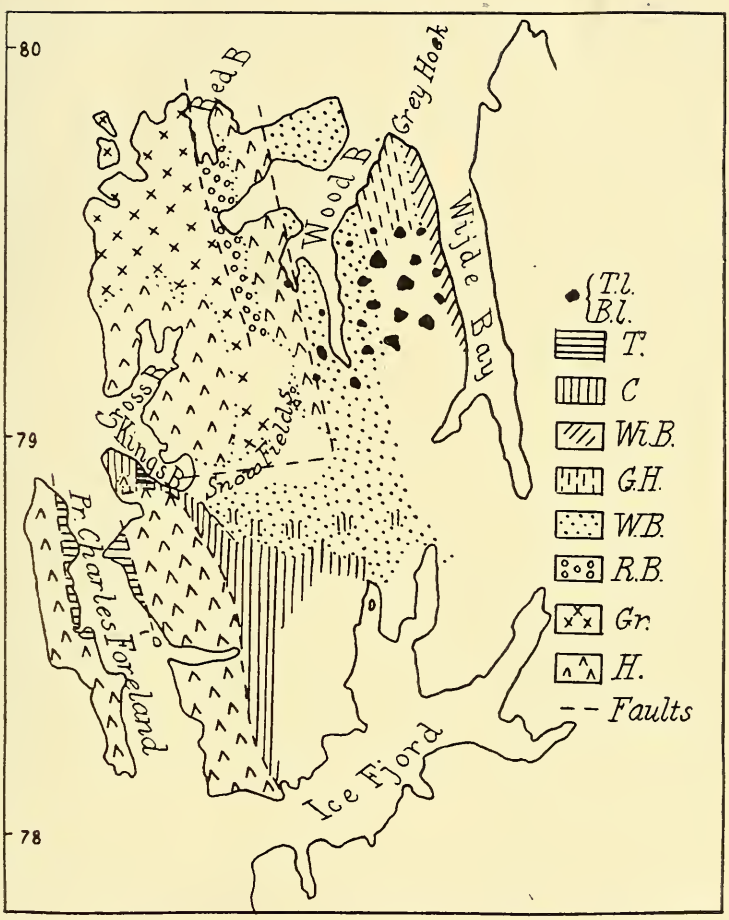


Fig. 2. Geological map (1:2,000,000) of the northwestern corner of Spitzbergen, by A. Hoel and O. Holtedahl. Based on the authors' observations, 1909–12.

T.l. = Trachydoleritic lava and tuff. *B.l.* = Basaltic lava. *T.* = Tertiary. *C.* = Carboniferous.

Wi. B. = Wijde Bay Series
G. H. = Grey Hoek Series } Devonian
W. B. = Wood Bay Series

R. B. = Red Bay Series—Downtonian

Gr. = Chief area of granites and gneisses. *H.* = Heclahook (metam. sedim. rocks).

Bay, we observed that there existed no simple boundary line between the large area of granites and gneisses in the northwest and the Heclahook phyllites, mica schists and quartzites farther south. On the contrary, we found the granitic rocks to occur as intrusive bodies in the metamorphosed sediments and to be therefore younger instead of older than the latter. We have here partly compressed igneous rocks, intruded before the intense folding of the Heclahook was finished, and partly unaltered granites of various types, of a somewhat later age. In these occurrences we have a striking parallel to the conditions in the northwestern part of the Scandinavian Peninsula, where in late years more and more of the granites and gneisses, previously regarded as of Archean age, have been proved to be younger than the metamorphosed sediments that probably are of Cambro-Silurian age.

As for the Heclahook system, we cannot here go into detail. We have worked a good deal with these widely distributed rocks, formerly very little known in our region, and found them to consist of a great number of different types of sediments. We have often met with conglomerates which, in at least one case, indicated the existence of dry land at one period of Heclahook time. The strike is generally NNW–SSE. Unfortunately, we, like earlier geologists, have not succeeded in finding fossils in this system, so we still have to rely on comparisons with Scandinavia and with Bear Island, where young Ordovician fossils are found in similar rocks, thus fixing the age of at least a part of the Heclahook as Ordovician, although the whole series may have representative formations of Cambrian to Silurian time. On the other hand, new evidence for fixing the uppermost possible chronological limit of the Heclahook has been obtained by our studies on the younger sedimentary series.

For their great thickness and wide distribution, the Devonian strata of Spitzbergen have been previously very little studied. It was known that the system consisted chiefly of red and green sandstones in which were found a few placoderm fishes, indicating Lower Devonian age, a large *Leperditia*, and undetermined plant remains. Then there had been found in one place a few Upper Devonian fishes, better plant remains, and an *Estheria*. Finally, a series of grey slates occurring at Grey Hoek, with new forms of lamellibranchs, had also been referred to the Devonian, although the exact stratigraphical position was unknown. The total thickness of the Old Red type of the Spitzbergen Devonian, the Grey Hoek beds not included, was estimated to be at least 1200 m., and perhaps more than 1500 m.

We have devoted a great deal of time to the Devonian, and hope to have established the chief features in its stratigraphy. They may be summed up as follows:

FIG. 3.

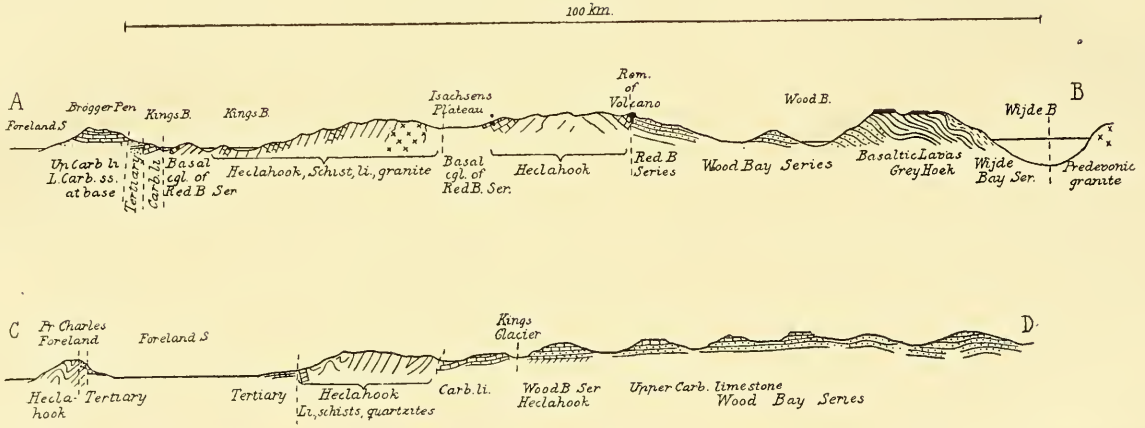


FIG. 3. Two sections from the northwestern corner of Spitzbergen. (Vertical scale exaggerated.) For location see the map, page 416.

Red Bay Series.—Resting upon the remnants of the Heclahook Mountains, we have found an enormous series of conglomerates, without doubt to a great extent of continental origin, and probably laid down in troughs in the still unbase-levelled surface. In many places we found the contact between the Heclahook and the conglomerate marked by huge sharp-edged pieces of loose rock that have not been moved at all, and that represent the fractured older surface. These may consist of granite, limestone, quartzite, and so on. Higher in the sections the rocks become smaller and more and more rounded, whilst the pebbles at the same time become exclusively quartzose. The color of this finer pebbled conglomerate is always deep red. The thickness of the whole conglomerate series is 500–600 m., in some places perhaps more.

Above the basal conglomerate lies a yellowish white, coarse, cross-bedded, unfossiliferous sandstone with a thickness of 100–200 m.

Conformably resting on this sandstone are the as yet oldest known fossiliferous beds of Spitzbergen, a series of mostly greenish, but in some layers red, sandstone, rich in mica, with a known thickness of about 2000 m., and containing in certain of the red layers an abundance of wonderfully preserved fishes, chiefly *Pteraspis*, *Cephalaspis*, and *Palæaspis* forms. Besides these, there occur very commonly lamellibranchs, a few badly preserved ostracods and some poor plant remains. Professor Kiär of Kristiania, who is working out our collections of placoderm fishes, states that the age of these fish-bearing sandstones seems to be equivalent to the Downtonian of the English standard. The mountain folding of the Heclahook and the subsequent erosion of the mountains must accordingly have occurred in pre-Downtonian time.

After the deposition of the Red Bay sandstone, some orogenetic movement—block faulting—probably took place locally, for in places the whole series was totally removed before the next known group of sediments was deposited.

Wood Bay Series.—In this series come the red to brown, partly green, often ripple-marked sandstones and shales that cover a very large area to the northwest, between the eastern part of the Ice Fjord and the north coast. From a great number of localities we have collected very interesting assemblages of Lower Devonian fishes, representing a large number of species belonging to the genera *Pteraspis*, *Cephalaspis*, *Acanthaspis*, and others. Furthermore, poor plant remains and a big *Isochilina* occur. The thickness of these sandstones is estimated to be about 3000 m.

Grey Hoek Series and Wijde Bay Series.—Without noticeable unconformity then follows the Grey Hoek Series, grey

slates with lamellibranchs, that are in turn overlain by the uppermost known Devonian sediments, grey sandstones and shales with Upper Devonian fishes, plant remains, and some ostracods, among others a big *Isochilina*. The total thickness of the two series is estimated to be at least 4000 m. The younger of the two has its main distribution on the west side of Wijde Bay, and may be named the Wijde Bay Series. Here probably belong the Upper Devonian slates found by Nathorst at Klaas Billen Bay in the Ice Fjord.

This is not the place to go into the far-reaching discussion as to the mode of deposition of this vast amount of Devonian sediments, the total thickness of which is about 10,000 m. A fact that is, however, to be noted is the occurrence of fossils of marine types, such as the big ostracods and some of the lamellibranchs, along with the fishes in each of the four thick series. In this respect, the Old Red system of Spitzbergen differs from that of Scotland, which it in general much resembles.

We have:

In Spitzbergen	*In Scotland*
Wijde Bay Series	Upper Old Red
Grey Hoek Series	Middle Old Red (Orcadian)
Wood Bay Series	Lower Old Red (Caledonian)
Red Bay Series	Downtonian

Both the Grey Hoek Series and the Orcadian differ lithologically from the usual type of Old Red in consisting chiefly of grey and argillaceous material.

We know from the Swedish investigations that the Devonian has been locally deformed in pre-Carboniferous time, and we therefore must assume that there is a break in sedimentation between the two systems, although unfortunately the boundary between the Wijde Bay Series and the Carboniferous has as yet not been seen. This lack of knowledge is in part due to the fact that the Upper Devonian and the Lower Carboniferous are lithologically very similar and poor in fossils, rendering stratigraphical distinctions difficult.

The Carboniferous of northwestern Spitzbergen has been studied in some detail, and two papers on that subject have been published recently.* On this occasion, we need only mention some few facts. The Lower Carboniferous plant- and coal-bearing sandstone was found to be much greater in thickness than was formerly supposed. At the mouth of the Ice

* Olaf Holtedahl: "Zur Kenntnis der Karbonablagerungen des westlichen Spitzbergens. I. Eine Fauna der Moskauer Stufe," Videnskapsselsk. Skrifter, I. Mat.-Naturv. Klasse, Christiania, 1911; "II. Allgemeine stratigraphische und tektonische Beobachtungen," loc. cit., 1912.

Fjord, a thickness of 1200 m. was measured, without attaining the base of the system.

After the deposition of this sandstone, great movements took place. At one locality we find that not only had the Carboniferous sandstone been eroded away, but nearly all of the Devonian as well, since only 200 m. of the Wood Bay Series was left. The Wood Bay Series rests directly upon Heclahook schist, as the Red Bay Series was probably eroded away in still older time. These occurrences are very similar to those on Bear Island to the south, and tell of continental conditions and of enormous denudation in Devonian and early Carboniferous time.

As to the time of the first invasion of the sea after this long continental period, we have been able to fix it very definitely by the discovery at one place of a rich fauna at the base of the elsewhere very poorly fossiliferous "Cyathophyllum limestone." The fossils proved to be older than any of those previously known in the marine Carboniferous of Spitzbergen, and indicate the Moscow horizon, of Middle Carboniferous age, according to the Russian classification. The basal limestone beds are often developed as compact coral masses several meters thick, resting upon a conglomerate of small quartz pebbles that in turn conformably overlies the Lower Carboniferous sandstone. The average thickness of the whole marine Carboniferous and Permo-Carboniferous series is 1000 m.

Permian beds are found in a few localities in northwest Spitzbergen, but show no new features. If we accept the thickness of the Permian as given by the Swedish geologists, namely, 300 m., the whole thickness of the Palæozoic sediments younger than the Heclahook is as follows :

Permian	300 m.
Carboniferous	2,200 m.
Devonian, about	10,000 m.
Total	12,500 m. (=12·5 km.)

The Mesozoic formations are not represented in the northwest corner, except near the Ice Fjord, where they have been studied by the Swedes.

As for the Tertiary beds, we have discovered a new area on the west coast, between Kings Bay and the Ice Fjord, and fixed the distribution and mode of occurrence of the previously known areas.

The Quaternary deposits and the glaciers have been studied very thoroughly by Mr. Hoel, and the height of numerous marine post-glacial terraces has been measured, showing the highest level of the sea to have been 130 m. Each year the

exact advance of a big glacier at Cross Bay, the Liliehook Glacier, has been noted. A large stone placed on the surface of the glacier 200–300 m. from the margin advanced: 1908–9, 338 m.; 1909–10, 200 m.; 1910–11, 183 m.; 1911–12, 77 m.

The chief tectonic features can be seen from the geological maps and the sections. The general direction of the fault lines is NNW–SSE, parallel to the strike of the Heclahook rocks.

Regarding the age of the dislocations, the Red Bay fault is probably very old, as the red Wood Bay beds, farther south, do not seem to be affected by it. The down faulting of the Tertiary areas, and probably the big fault along the west coast, are of post-Miocene age. There was observed, however, in Prince Charles Foreland, a feature that seems to indicate that this great dislocation has continued since an older time. The Tertiary beds are there seen to rest directly upon the Heclahook, all the younger formations having been eroded away in pre-Miocene time. This erosion is therefore most naturally explained by an early uplift of this western region.

An interesting feature in connection with the big fault that separates the Heclahook horst on the east of the Foreland Sound from the great eastern down-sunken area, is the tectonic disturbances near the fault line, telling of an immense tangential pressure. The finest illustration of this is seen on Brögger's Peninsula, where a great sheet of Heclahook schists is pushed several kilometers to the north over the Carboniferous limestones.

The age of the fault on the west side of the Wood Bay Series, running nearly in a straight line for 80–90^{km}, cannot as yet be fixed with certainty. There are several facts that seem to indicate an early pre-Carboniferous age, which would mean that we have here one part of the western limit of that Graben of which the pre-Carboniferous Wijde Bay fault is the eastern.

That the fault line has very recently been also a line of weakness is shown by the occurrence of young volcanic masses that in two places are situated directly upon it.* At one place, in Bock Bay, can still be seen the well-preserved remnants of a volcanic cone, 500 m. high, built up of lapilli and tuffs, often with bombs, and crossed by lava veins. The rock in these is trachydolerites, rich in alkalies, and thus different from the ordinary young volcanic rocks of the northeastern Atlantic region. The Bock Bay volcano is certainly of Quaternary age, as it is situated near the bottom of an ice-eroded valley, and the lava streams commonly contain boulders, originally belong-

*See Hoel and Holtedahl: Les nappes de lave, les volcans et les sources thermales dans les environs de la Baie Wood au Spitsberg, Videnskapsselsk. Skrifter, I. Mat.-Naturv. Klasse, 1911.

ing to the moraines of the glaciers of the Ice Age. The second volcanic cone is situated near the top of a mountain ridge farther to the south, and is much more dissected.

Additional evidence indicating instability along this same fault line is the presence of a large number of warm springs, with a maximum temperature of 29° Celsius, many of which have built up beautiful basins of carbonate of lime.

Covering all the higher part of the southern area of the peninsula between Wood Bay and Wijde Bay occurs another kind of volcanic rock. Here we find thick beds of basaltic lavas, often with a wonderfully well-developed columnar structure. Regarding the age of these rocks, their petrologic relation to the well-known Cretaceous or early Tertiary diabases of Spitzbergen may indicate synchroneity with the latter. Assuming a Tertiary age, we would also have contemporaneity with the basaltic rocks of the other north Atlantic countries. The physiographic features of the lava region also suggest a rather young age. We may for very long distances walk on the quite plane and smooth lava surface, as if the igneous material had flowed out only a short time ago. Yet we find a great number of ice-eroded valleys cutting through the lavas and far beneath them, showing that the lava must be older than the time of greater ice distribution, since at present the region is almost barren of glaciers. It seems, however, as if this lava land had not been at any time wholly ice-covered, as we know Spitzbergen in general has been.

The lava lies on an ideally plane surface, cut in the folded Devonian rocks. Probably the outflow took place when this surface was at, or near, sea-level, and later the whole region was uplifted, at the north end of the peninsula only 300–400 m., at the southern 1200–1300 m.

University of Kristiania, October, 1913.

Art. XXXVI.—*The Permian Geology of Northern Brazil;* by Miguel Arrojado R. Lisboa.

Introductory.—In 1909, when employed by the Serviço Geologico do Brazil to make a geological reconnaissance in the northern and northeastern states of that country, I was especially requested to investigate the supposed occurrence of *Psaronius* in the state of Piauhy.

The city of Pará was selected as a convenient starting point for the expedition, and in the natural history museum at that place I found a characteristic specimen of *Psaronius* not more than a decimeter in diameter. It was not labeled, but was reported to have come from the state of Maranhão, and to have been received as a gift.

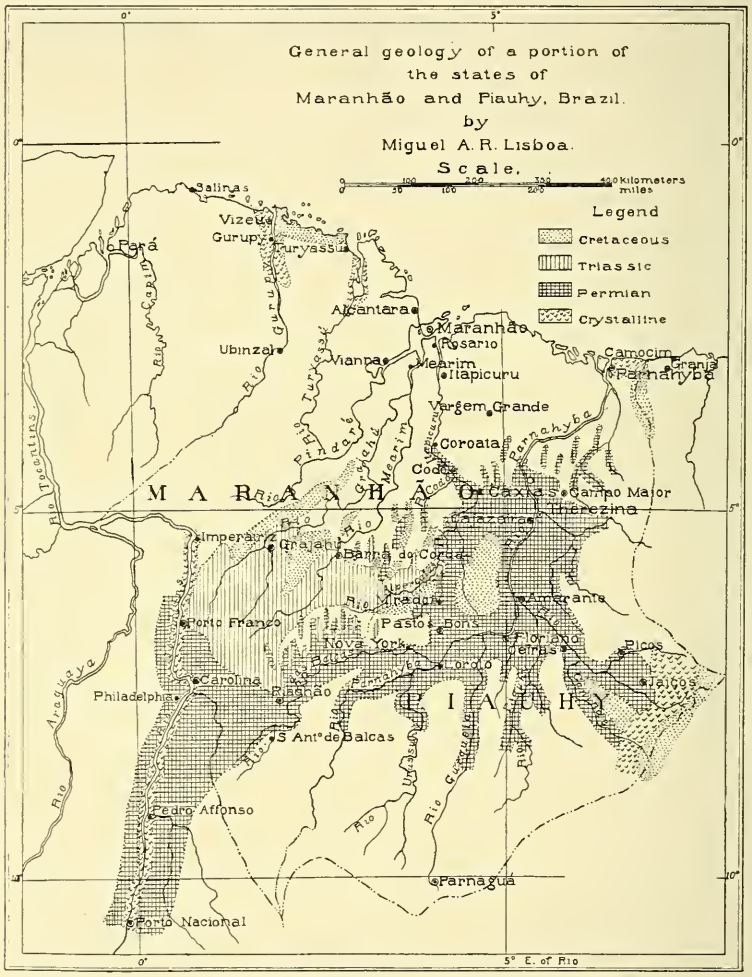
Afterwards I made inquiries in the city of Maranhão among the collectors of mineral specimens, and among the many examples of fossil plants examined, almost all of them angiosperms, I had the good fortune to find a trunk of a typical and beautifully preserved *Psaronius*, about 40 centimeters in diameter. This specimen was in the corner of a hall in the Episcopal Seminary and had long been used as a seat in the chapel or cathedral by the Rev. Alvarenga, late bishop of the diocese. Through the courtesy of the Rev. Galvão, governor of the bishopric, this fine trunk has been sent, at my request, to the collections of the Serviço Geologico do Brazil at Rio de Janeiro.

The locality from which it came was known only very vaguely. The Bishop had received it as a gift from the Rev. Manoel Gonçalves Ribeiro in the year 1889 or thereabouts, while making a pastoral visit through the province. The Rev. Ribeiro had died while vicar in S. Francisco, but I learned definitely that the trunk had originally been found in the region of the Parnahyba river above the city of Floriano.

With this and many other indications of geological occurrences of various natures, I was enabled to outline a trip, having in view a general geological reconnaissance of the state of Maranhão and of the north of Goyaz. This plan was successfully carried out. With the help of an assistant, the topographer Hans Baumann, I resolved to visit convenient points in the interior of the state, meandering it in directions approximately east-west and north-south, and having our traverses frequently tied up. Thus we would have an opportunity to observe the various beds of the Pindaré, Grajahú, Mearim, Corda, Alpercatas, Itapicurú, Balsas, and Parnahyba rivers in different places, and at the same time to examine, in the stream channels, the underlying sediments which are elsewhere covered with sand.

The following program was carried out. I went up the Itapicurú alone as far as Codó, crossed its divide with the Mearim and reached Barra do Corda, and later the Grajahú

Fig. 1.

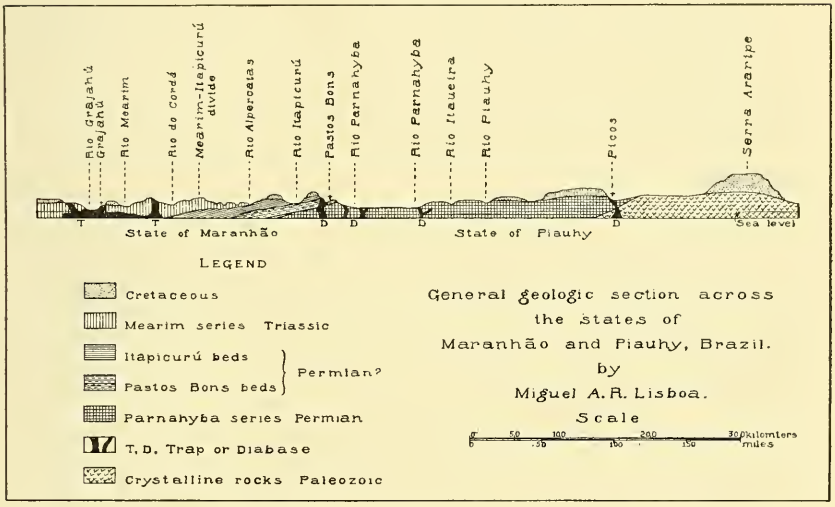


river. Turning to the southeast I crossed the upper Mearim, the Corda, Alpercatas at Mirador, and the upper Itapicurú, and then, after passing through Pastos-Bons, reached the Parnahyba river above Floriano. I then followed this river to Therezina, crossed its divide with the Itapicurú in the

vicinity of Caxias, and then crossed the northern part of Piauhy by way of Livramento, Campo Maior, and Peripiri. I then passed the Serra Geral, S. Benedicto, and finally Viçosa and Camocim in Ceará.

My assistant, Mr. Baumann, went up the Mearim to Pedreiras and Barra do Corda and reached Grajahú, where we had arranged to meet. From there, crossing the plateau which forms the watershed of the Pindaré, he examined the lowlands of the Tocantins at Carolina, and turning to the east reached the headwaters of the Parnahyba at Riachão and the Balsas at

Fig. 2.



Santo Antonio. He then crossed the plateaus which flank the Chapada das Mangabeiras and form the divide between the Parnahyba and the Tocantins rivers, crossing the rivers Manoel Alves Grande and Manoel Alves Pequeno and reaching Pedro Affonso and Porto Nacional, in Goyaz, from which place he followed down the Tocantins to Pará.

This exploration led to the discovery of a great many localities where *Psaronius* occurs in the states of Maranhão, Piauhy, and Goyaz, and consequently to the verification of the presence of an extensive Permo-Carboniferous zone in these northern states. And at the same time it was not only possible to observe in detail the structure of the upper Permian, but also to recognize another series of sediments between that horizon and the Cretaceous which is indicated by the presence of silicified

dicotyledonous woods. Diabasic eruptive rocks of different types were also discovered, occurring in a manner similar to those in the south of Brazil. In the absence of paleontologic evidence, these eruptives suggest the provisional placing of certain overlying reddish sedimentary beds in the Triassic. The area of Cretaceous sediments in the states of Piauhy, Maranhão, and Goyaz has been considerably limited. For the greater part, the interior of the first two of these states and a large part of the third is made up of upper Paleozoic and lower Mesozoic sediments which only future study and paleontological studies can definitely outline.

Localities of Fossils.

In the course of the exploration many fossiliferous localities were discovered. Most of them are referred to here.

1. *Marine mollusca.*—Marine shells were seen in Carutapera, between Turyassu and Gurupy, on the western part of the coast of Maranhão. They are of Cretaceous age, and very probably of the same geological horizon as those of Piabas in Pará.

2. *Dicotyledonous woods.*—Silicified woods were found in the high plateau regions of Grajahú and Mearim. These plants are of common occurrence in this region, and are well known to the inhabitants. They are called *Capitão do Campo* (Captain of the campo), which is the name given to a tree common in the campos of the north. Specimens were collected in place at the following localities :

(*a*) At Fazenda do Torto, nine kilometers from the city of Grajahú, I made a collection of material in place. The specimens sent to the Serviço Geologico are parts of a large trunk imbedded in grayish quartzitic sandstone five meters below the surface of the ground. In certain parts of the trunk, deeply buried and attached to the sandstone, could be seen zones of different textures and colors, crossing indifferently the quartzite and the silicified trunk. This indicates that the silicification in this particular case occurred where the fossil was found; its original resting place was therefore the quartzitic sandstone of Torto.

(*b*) Fazenda da Coelho, twenty-four kilometers down the river north of Grajahú.

(*c*) Fazenda Monte Alegre, twelve meters to the northwest of Grajahú.

(*d*) Fazenda da Extrema, six kilometers to the south of Grajahú.

In these localities all of the specimens found are of dicotyledonous woods.

3. *Lowlands of the Parnahyba.*—In the region of the Parnahyba river in the states of Maranhão and Piauhy, silicified dicotyledonous woods occur very abundantly and usually associated with conifers or with *Psaronius.* Along the channel of the Parnahyba specimens were found in the high banks of the lowlands which border the river.

Whenever it was possible to determine the conditions of the peculiar association it was found that these silicifications occur in a recent conglomerate, in which I could identify, with certainty, detritus or pebbles of rocks from the different strata of the region, ranging from the Permian up. These woods show by their rounded surfaces, positive signs of transportation. I found with them on the surface of ground trunks of dicotyledons which I believe to be Permian, but without any traces of rounding through erosion, or indicating, at most, very little transportation.

This is explained by the occurrence of Cretaceous chapadas very near the river and probably covering the Permian sediments. The slight erosion due to transportation for a short distance is sufficient explanation of the occurrence of these silicifications on the bank of the river and above the Permian. The dicotyledonous trunks showing evidence of an almost imperceptible amount of transportation which are found at Pedras, twenty-four kilometers south of Floriano, lie in a residuary sandy soil derived from the Permian sandstone.

Under the circumstances above described fossil dicotyledonous woods occur in the following localities:

(*a*) Surubí on the Parnahyba river, between the "grota do Mendes" and Floriano, close to a sheet of compact diabase.

(*b*) Pedras, twenty-four kilometers south of Floriano, on the Maranhão bank of the Parnahyba.

(*c*) In the vicinity of Floriano on the Maranhão bank of the Parnahyba.

(*d*) Alagoas, five leagues from Amarante (?) (Specimens donated and the location doubtful.)

(*e*) Neighborhood of Amarante in Piauhy.

(*f*) Logoa near Floriano on the Maranhão bank of the Parnahyba river.

Gymnosperm phanerogams.

(*a*) *Conifers.* Trunks of conifers in the "grota do Mendes," associated with *Psaronius.* These were collected by me from a gray sandstone directly overlying marly calcareous disintegrating shales along the bank of the Parnahyba. There is no doubt that these fossils were collected in their original resting place.

This explains the unsuccessful attempt to find dicotyledonous fossil woods in this locality. And it proves that conifers occur with *Psaronius* in the Permian. The occurrence of these gymnosperms with dicotyledonous woods in the north of Brazil must be considered as a geological accident due to recent transportation.

Cryptogams.

(*b*) At Codo in Maranhão conifers were found on fazenda União after my visit and in compliance with my request.

Psaronius. Beautifully preserved specimens of *Psaronius* were collected by me in Maranhão and Piauhy, and by Mr. Baumann in Goyaz and also in Maranhão near the Tocantins.

We collected specimens from the following places:

(*a*) Chapada do Jabotí, in Maranhão, near the Parnahyba, between Nova-York and Floriano.

(*b*) In the "grota do Mendes" not far from the above locality. They are there associated with conifers.

(*c*) In the bed of the Poty river a little above its mouth, at the road leading from Therezina to Campo Maior.

(*d*) In the streets and public squares of Therezina.

(*e*) In Livramento near Campo-Maior about 56 kilometers northeast of Therezina.

(*f*) In the neighborhood of the village of the Crahos Indians, on the divide between the Manoel Alves Grande and Manoel Alves Pequeno rivers, in Goyaz.

(*g*) On the fazenda of Burytisal, west of the Tocantins, seventeen kilometers from Porto Nacional in the central part of Goyaz.

(*h*) Near Carolina on the Tocantins in the state of Maranhão.

Still other localities with *Psaronius* were noted by me, or by the inhabitants of the regions visited, but in none of these was it possible to determine the stratigraphic conditions under which the fossils occur.

(*i*) In Carnaúba de Pedra, forty-eight kilometers from Flores, which is on the bank of the Parnahyba opposite Therezina.

(*j*) Along the Cajaseiras line, not far from Flores, silicifications characteristic of Permian beds seem to occur together with plant remains which I judge to be the central woody part of a *Psaronius*. The occurrence of *Psaronius* in the region explored is not only very common, as is shown by the discoveries made, but is also generally known to the inhabitants, who readily distinguish the *Psaronius* from the phanerogams which are of common occurrence to the northeast. "*Carnaubeira petrificada*" (petrified palm) is the ordinary name given

to the fossil. This erroneous identification of the woody central roots of *Psaronius* with those of the fibro-vascular bundles of the carnaubeira (*Copernicea cerifera*), abundant in the region, not only shows the observant character of the inhabitants, but also affords a relatively safe basis for the provisional identification of fossil woods occurring in localities not examined.

5. *Fossil fishes.*—In the Pastos-Bons region, according to information furnished by the inhabitants, there are fossil fishes. I was given, in that locality, a piece of the backbone of a fish, as yet unclassified, but I have no information in regard to the character of the beds from which it comes.

In this zone there should occur the contacts of two or three series of sediments, as will be seen farther on. The identification of this fossil will probably determine the geological age of the sediments of Pastos-Bons, and further study will permit a better discrimination of the beds.

6. *Fish scales.*—In Floriano I got some ganoid fish scales that came from Frasqueira, seventy-two kilometers from Floriano, but the locality could not be examined.

Paleobotany.—All the specimens of fossil plants found were silicified, and at times they were beautifully preserved. Dr. Orville A. Derby submitted the specimens we collected to Count Salms-Laubach, who made a detailed paleobotanical study of them and pronounced them to be Permian types. This study gave evidence of the existence of various types of *Psaronius.* It is to be noted that specimens of *Psaronius* are still found in place in the purple sandstone of the Jabotí tablelands above the gray sandstone containing conifers and *Psaronius* of other types.

These were in the base of sandy sediments which overlie marly shales containing calcareous layers.

From the erosion of the gray sandstone beds there resulted the accumulation of the silicified plants on the surface of the lower slaty shales. The discovery of a great number of these localities at considerable distances apart, made in a hurried reconnaissance and the presumption that different types correspond to different localities, as well as the incomplete study of poorly preserved specimens, emphasize the importance, from a paleobotanical point of view, of the study of the Permian plants of northern Brazil. The great extent of these sediments in the north is also noteworthy.

In every locality where conifers were found in place I have found that they either accompany the *Psaronius* and come from the same sedimentary deposit, or else were isolated and not accompanied by other fossil plants.

In no undoubted Cretaceous locality did I find conifers asso-

ciated with dicotyledonous woods. Silicified conifers are abundant in the south of Brazil, not only associated with *Sterioster-num tumidum* Cope, of the Permian, but very probably with *Psaronius* also.

Characteristic Geological Features.

In the absence of paleontologic evidence, some special features of the rocks and of the geology in the north permit a provisional determination of the age of certain sediments. Thus the nature and mode of occurrence of the eruptive rocks, as well as the presence of siliceous beds or concentrations in limestones and other rocks, or in the pebbles of conglomerates derived from these materials, are very characteristic of certain Triassic or Permian sediments.

Eruptive rocks.—Two different eruptive rocks cut the pre-Cretaceous sediments in the region explored. Both are diabasic and differ from each other in their textures, which seem to have a definite relation to the more or less recent age of the beds which they cross. Observation here showed that the presence of these two types seems to have a definite relation to the age of the sediments just as in the south of Brazil.

The compact diabase.—This black, eruptive rock is a normal diabase which crops out in the bottom of the valleys where erosion has exposed beds older than the Psaronius-bearing sandstones. It occurs in two manners:

1. In place, forming dikes or sheets which crop out above the marly shales. These eruptives form the base of the Permian sandstones with *Psaronius* in the channel of the Parnahyba river. In Surubí, in Coroa do Pinga, and in other points along the Parnahyba, it forms the rapids of the river; in Amarante it seems to form a sheet in the lower part of the Permian sandstones. At Picos Dr. Roderic Crandall has observed this same rock cutting through the argillaceous shales and outcropping in the lower zone of the eroded red sandstone. Dr. G. A. Waring and Dr. Manoel Arrojado Lisboa have also noticed this type under identical stratigraphic conditions on the upper Poty, directly behind the scarps of the Serra Geral.

2. The same rock is also exposed in great rounded blocks scattered over the surface of the Permian sandstone areas. These accumulations of blocks bring to mind glacial bowlders, but very likely they merely result from the rapid decomposition of the diabase.

(b) *Trap.*—The other eruptive is also a pyroxene-bearing rock with plagioclase, but is commonly amygdaloidal and rich in zeolytes. It represents a later eruptive phase of the same diabase (?). This rock occurs in Grajahú in a large flow. It

was seen over a large area in the vicinity of that city occurring not only above Grajahú but also in the divide between the Itapicurú and Tocantins rivers, near Carolina on the Tranqueira river. This type of eruptive also appears in the high divides between the Mearim and the Corda and between the Corda and the Alpercatas. It forms sheets between beds of red sandstone, correlated in his paper with the Triassic as was done in the south. In no part of the north of Brazil have eruptives been seen cutting Cretaceous sediments.*

Siliceous beds, pisolitic sandstones and cherts.—Pisolitic siliceous formations occur among the upper Permian sediments. There are also opal beds in the limestones and the argillaceous shales which underlie the *Psaronius* sandstones. These siliceous rocks, accompanied by the disintegrated material of the rocks which contain them, are scattered in the form of bowlders over the surface of large areas, giving a reasonably safe indication that they are derived from definite sediments. The same thing happens in the case of certain siliceous concentrations (silicate of iron?), light green in color, from the amygdaloidal eruptive rock, which either form, as bowlders of decomposition, a surficial bed over large areas, or else separate the eruptive from the overlying sandstone.

Such occurrences have not been found in the Cretaceous sandstones. The Cretaceous sediments in northern Brazil are essentially sandy, and as they approach the Triassic and the Permian they become more and more clayey.

The facts to which I have referred, and the study of the geology along certain sections, made it possible to separate for the first time the geologic sediments of northern Brazil in the states of Maranhão, Piauhy, and Goyaz.

The Permian and Post-Permian Rocks.

The discovery of *Psaronius* in the states of Maranhão, Piauhy, and Goyaz, and of fossil dicotyledonous plants in Maranhão, permits the identification of extensive beds of a great system of sediments in the north of Brazil. In the absence of paleontologic evidence, the post-Permian or pre-Cretaceous beds could only be separated with much uncertainty. The characteristic features of the rocks of one series and their analogy with the sediments of southern Brazil led me to refer it to the Triassic.

Upper Permian Parnahyba Series.

The Permian sediments with *Psaronius* were first identified by me in the plateau of Jabotí and in a little brook known as

* The sedimentary beds of the Abrolhos covered by eruptives were referred by Hartt to the Cretaceous. There is no certainty, however, about the age of the Abrolhos beds.—*J. C. Branner.*

the "grota do Mendes" which runs from that plateau to the Parnahyba. This locality is in the channel of the Parnahyba river between Floriano and Nova York.

Shales.—The sandy Permian formation in the section examined rests upon ashen gray marly shales and calcareous beds, and is capped by a thin layer of conglomerate. A thin yellow residual intercalated rock seems to be derived from a limestone. These rocks outcrop in the "grota do Mendes" and form the bed of the Parnahyba river in that region. They are there covered by a gray sandstone, but they were not seen elsewhere.

The Mendes sandstone.—The Mendes sandstone overlies the shales. It is an ashy gray sandstone grading to white in its upper part. It outcrops at the level of the banks of the Parnahyba, and contains in the "grota do Mendes" a great abundance of *Psaronius* and conifers which were collected from the same bed. Some of them have the same dark color as the rocks. The upper part of this sandstone is white, friable, and is probably the rock which forms the marginal plains of the Parnahyba, down stream to Floriano and beyond.

Along the roads overlying this rock and forming the surface is a recent conglomerate, containing trunks of dicotyledonous plants derived from a later sandstone of the plateaus.

The red sandstone of Jabotí.—The Jabotí sandstone is red with purple spots. It overlies the formation just described. The large and beautiful specimens of *Psaronius* which I collected are from the low plateau of Jabotí. Some of them are forty centimeters in diameter, and beautifully preserved. I collected *in situ* part of a trunk, which I preserved, incrusted by the sandstone of the plateau. The other three specimens came from this same trunk, but the material in which they were imbedded had been removed before my visit.

On examining the material from a well which was being dug at this time in Floriano, I noticed that a layer of sandy shales of a chocolate-red color separated the gray sandstone of Mendes with six meters of thickness from the red sandstone of Jabotí. Although these appeared to be distinct, it seems best to include them with the Jabotí sandstone because it appears that these beds of shale occur frequently in other localities intercalated in this red Jabotí sandstone, which has a great development, and extends north and south forming the second bottoms of the Parnahyba river.

In Amarante the river cuts a range of plateaus with an escarpment 150 meters high. They are made up of white and red sandstone with pisolitic concretions. In the lower part they contain flows of normal diabase.

The chapadas which are seen farther on in Castelhana are of the Jabotí sandstone. This same sandy formation continues

east and west of Therezina, usually argillaceous, but always containing the pisolitic sandstone, passing in some places to a true clay, called *tauá* by the inhabitants of the region.

The *Psaronius* from Livramento was found in a cultivated field among the surface pebbles, already detached from the rock, which is here a very clayey and friable sandstone. An examination of the escarpments of the surrounding elevations showed that they were formed of the same red sandstone. *Psaronius* was also collected from red sandstone in the Balsas river in the extreme south of Maranhão; in Carolina, and in the lowlands of the Tocantins, and, according to the notes of Baumann, in the Manoel Alves Pequeno and Manoel Alves Grande rivers in Goyaz, and at Porto Nacional west of the Tocantins.

Pisolitic rock.—A characteristic feature of the Permian sediments is the common occurrence of a pisolitic rock. This was first noticed in Riachão Fundo, near the "grota do Mendes" at the contact of an overlying ashy gray sandstone with the Jabotí sandstone. There the two sandstones are separated by thin flinty beds, light in weight, chocolate-colored and with seed-like grains. This rock seems to be derived from the alteration of a pisolitic limestone whose carbonate of lime has almost completely disappeared. As a rule, however, the pisolitic rock is a hard white sandstone irregularly interbedded in the Jabotí red sandstone.

S. Bartholomeu sandstone.—The S. Bartholomeu sandstone is ashy gray, in places friable, in others it is hard or glassy, and quite commonly false-bedded. It was seen near the little river of S. Bartholomeu, not far from a locality where *Psaronius* was found. It occurs along the road from Pastos-Bons to Riachão Fundo, where it has a thickness of about fifty meters.

The Pastos-Bons beds.—The gray sandstone of S. Bartholomeu is overlaid by a series of rocks, generally green and chocolate-colored in alternating layers, and made up of shales and white calcareous layers with an intercalated white sandstone.

These beds were first seen in the vicinity of Pastos Bons, and they are well exposed in the neighborhood of that city in the beds of streams draining into the Parnahyba.

The limestones of the series are rather thin and contain many layers of opal, and, like the shales, they are alternately chocolate-colored and green. On top of these beds the lime rock is thicker and is well exposed at the colony of Gangorra near Pastos Bons, where they have a thickness of three meters and are of a beautiful green color. Without doubt this is the same thin limerock that outcrops at different places in the Parnahyba basin.

There is a limestone with this same thickness of three meters

at Caieira, station of Aarão Reis on the Caxias-Cajazeira railway, which I correlate with that of Gangorra. It is in the same Permian zone of abundant silicifications of *Psaronius*, and it is noteworthy for having its surface eroded at the contact with the overlying sediments, as I was able to verify in a recently opened quarry. This shows a long period of erosion before the deposition of the overlying beds.

At Caieira this limestone marks a genuine nonconformity and must represent the top of the Permian. The overlying sediments are red clays which alternate with white sands that extend to the coast and are supposed to be of Cretaceous or Tertiary age.

At Gangorra the top of the limestone was not seen in contact with the upper sediments that seem to overlie them conformably and which are the Cagado sandstones on top and Croatá sandstones beneath.

The Cagado sandstone.—The Cagado sandstone is rather thick and uniform in appearance. In the latitude of Pastos Bons it forms the middle parts of the plateau escarpments on the sides toward the Parnahyba. It is everywhere marked by peculiar big white and red splotches that characterize the limits between the upper Permian and the lower Triassic of Brazil. Dr. I. C. White mentions this peculiarity of the sediments of Rio do Rasto, which he regarded as of lower Triassic age. The repetition of this phenomenon in northern Brazil in the sediments overlying Permian beds containing *Psaronius* just as they do in southern Brazil, is worthy of note. Some years ago I saw the same phenomenon in still another remote region in Brazil almost at the base of the escarpment of the Triassic plateau of Matto Grosso in the valley of the Aquidauana. Those sediments I now recognize as probably synchronous with those of Cagado in Maranhão, and with those of Rio do Rasto mentioned by I. C. White in southern Brazil.

The Cagado sediments extend throughout the basin of the Itapicurú in the latitude of Mirador.

The Croatá sandstone.—Above it is a rose-colored sandstone spotted with white and even grading into white with intercalations of shales which make a yellow clayey soil. This variegated rose-colored sandstone is well exposed in the village of Croatá.

The Mearim Series (Triassic?).

The upper beds are composed principally of red sandstone and include flows of amygdaloidal trap. These are probably synchronous with the beds which Derby has considered Triassic in S. Paulo and Paraná, and which I. C. White regarded as the upper member of the S. Bento series in his Santa Cathe-

rina system. These sediments extend from Alpercatas to Grajahú.

The Corda sandstone.—The Corda sandstone is greatly developed in the upper Mearim and also in its tributary.

In that region a large number of small, red, table-topped hills are scattered about in the extensive plains which form the terraces of the channels of these two rivers. They are here isolated, here in alignment, or perhaps bunched together in a sort of labyrinth, separated by uniform channels planed down, with regular slopes, in some places winding, and called *boqueirões* by the inhabitants. These give the region a characteristic physiographic appearance.

The sediments are uniformly sandy and red except at the contact or near the flows of the eruptives. Between the Corda and Alpercatas rivers, at Manoel Theodoro, the red sandstone becomes quartzitic. In the high divides there are eruptions of trap.

The thickness of this sandstone of Corda is at least 100 meters. At Grajahú a bed of coarse conglomerate with flint covers a flow of eruptive rock which forms an extensive sheet on top of the red sandstone. In the Serra Vermelha this bed seems to be covered by a red sandstone.

The Serra Vermelha is made up of the front wall of the plateau in the marginal plain of the Grajahú above the city of that name. Here it can be seen that the beds dip locally in a west-northwest direction. The thickness of the red sandstone beds and the included trap is 235 meters. On this sandstone there lies unconformably a yellow, friable sandstone which was included in the upper series of Cretaceous sediments.

The Grajahú Series (Cretaceous).

The Crajahú series is quite thin. It is composed of two types of sediments, a yellow friable sandstone covered by a quartzitic sandstone, with silicified trunks of dicotyledons. It forms the top of the plateau of Grajahú.

The Cretaceous of the interior seems to extend uninterruptedly to the coast, the sediments being argillaceous in some places and sandy and friable in others. At Carutapera in the extreme northwest of Maranhão I observed a fossiliferous limestone with a fauna similar to that of Piabas. This shows therefore the existence of marine Cretaceous basins on the coast of Maranhão.

Other Sediments.

Certain sediments were observed under such conditions that it is difficult to locate them in the geologic column of the region. Among these is a series containing bituminous shales

and certain calcareous, sandy, and marly beds in the middle parts of Rio Itapicurú and Rio Mearim, and in the lowlands of northern Goyaz.

These bituminous shales are associated with limestones on the Itapicurú river, near Codó, on the Rio do Inferno, in Igarape Santa Anna (Fazenda União), in Igarape do Codosinho, and on the Mearim river at the city of Barra do Corda. A single specimen of a coniferous plant from Fazenda União does not fix the age of these sediments, which present much the same features in all of their outcrops.

Bituminous shales of Codó.—The bituminous shale of Codó has been known since the exploration for the telegraph line from Capanema. The log of a well eight meters deep on the União estate, river Sant' Anna, shows from top to bottom the following beds:

Log of a well at Fazenda União.

6·	laminated sandstone
0·1	limestone
0·1	shale
0·5	limestone
0·2	black shale
0·2	limestone
1^{cm}	bituminous shale continues in depth.

It dips about 12° to the north.

In the Igarape do Codosinho, the total thickness of the calcareous, bituminous sediments is six meters. They overlie a white, soft, coarse-grained, loosely consolidated sandstone. The occurrence at Ribeirão do Inferno is the most interesting.

At Igarape do Inferno the sediments dip about 30° to the south and strike east and west. I have measured a thickness of twenty centimeters; the total thickness is probably more than fifty centimeters.

The lower sediment is a boghead coal, similar in appearance to the Marahú shale of Bahia. It overlies a thick bed of well laminated bituminous shale made up of distinct materials; black bands with intercalations of a bituminous material, composed of shiny grains, resin-colored and rounded, in the midst of an ashy gray to dark gray mass apparently formed of the same material as the shales. This material has not yet been studied.

In the bed of the Mearim river the bituminous shales are also covered by a limestone, with gypsiferous intercalations and siliceous beds parallel to the bedding, which dips to the south. A flaggy sandstone overlies the limestone with a thickness of more than fifty meters. A conglomeritic flint (?) bed

seems to separate these two sediments, although it was not possible to make any conclusive observations in this regard.

In Grajahú the same gypsiferous limestone of Mearim outcrops, but without the bituminous beds, which, if they occur at all, are below the level of the river. It dips to the north-northeast and is covered successively by red conglomeritic sandstone and by quartzite. The strike is N. 60° W. Near this place are the eruptions of trap already described.

In the Grajahú river the gypsiferous limestone clearly dips to the north-northeast and underlies the red sandstone sediments, supposed to be Triassic, which are cut by the amygdaloidal diabase. It (the limestone) outcrops, showing a thickness of twenty-five meters, near the base of a little chapada capped by a red quartzitic sandstone which is supposed to be the same as the Cretaceous sandstone of Torto.

A bed of limestone bowlders apparently separates these sediments from the red sandstone.

The notes of Baumann show that these bituminous and gypsiferous shales are exposed under similar conditions in Goyaz at the confluence of Rio Sereno with Rio Manoel Grande on the Tocantins lowlands.

Between Codó and the Barra do Corda are plains and lowlands without topographic inequalities to facilitate geological observations.

In the lowlands the soil is usually covered by iron-cemented rock, and since the character of the rains and the topography are favorable to great annual floods, the ground is frequently covered by alluvial detritus which prevents the observation of the older sediments. For this reason the geological observations made in this region are but scanty.

The following observations seem to merit mention, however.

The road from Codó to Barra do Corda, after crossing the bituminous shales, continues, between Fazenda União and Boa Esperança on a lower white sandstone, immediately underlying the bituminous shales. From Boa Esperança to the village of Pão Douro, a two days' journey, is a hopeless traverse for the geologist. There is only bog iron ore and sandy soil without rock outcrops. The road climbs to the village of Poços, the white sandstone disappearing and being succeeded by a red sandstone in the form of bowlders in the soil, but showing good stratification. The ground there begins to be broken by table-topped hills. The sediments are soft. The land continues to rise, but always gradually, to Cruzeiro, and beyond to the Serra da Boa Vista. The Serra da Boa Vista is the edge of a plateau which continues to the flanks of Almeida on the Itapicurú.

With a fall of about 100 meters the road descends along the steep edge of the plateau toward the village of Poços, which

has an altitude of about 100 meters. It is in this region that a very ferruginous calcareous sandstone, or sandy limestone, appears. Little bowlders of this limestone are strewn along the road for great distances. They remind one of a bed of brecciated conglomerate, loosened at the surface but composed exclusively of limestone. In this respect, this sediment is similar to those of Grajahú; the bed with blocks of limestone covers this gypsiferous rock, and the eruptive flows separate it from the overlying sandstones.

The limestone continues about eight kilometers beyond Taboa do Raymundo Felix. From there on there are abundant flints and a quartzitic sandstone which grades to a white sandstone of a reddish or yellowish tinge. Between Fazenda Moreira and the Clemente is a bowlder bed, the flints of which strew the ground. Like those of limestones and of the eruptives of Grajahú, these fragments of rock, laid on the surface of the ground, seem to come from a nearly horizontal sedimentary bed which contains them, cropping out along the surface of the ground. They bring to mind a breccia of disintegrated sandstone.

The Chapada do Corda rises from 100 to 120 meters on an average, and falls away about 80 meters on the side overlooking the city, near the river. At the base of the chapada, in the channel of the river, the bituminous shale appears beneath the limestone with its siliceous beds.

The descriptions given above will enable those who are acquainted with the Permian geology of both northern and southern Brazil, taking into consideration the neighboring occurrence of the Parnahyba series, to consider these limestones and sandstones with flints and siliceous laminations as Permian.

The difficulty of placing these sediments in the geologic column in the Maranhão system lies in the impossibility of recognizing the direct relations with the Permian sediments of Therezina or of the tableland which separates Caxias from the Parnahyba. In the Grajahú region also the succession of the sediments is not very clear.

There are bituminous schists in the Cretaceous in Ceará, at the base of the Araripe beds, near a basal limestone, and near this same limestone is a gypsiferous bed, two leagues from Santa Anna, on Fazenda Angicos. This occurrence has not been examined by a geologist and the stratigraphic relation of the sediment is not yet known.

The examination of the bituminous shales of Inferno and a rapid reconnaissance between Codó, Caxias, and Therezina will easily solve this important problem of the geology of Maranhão.

The calcareous and sandstone sediments with flints of the Poços limestone and the Cigana sandstone show the age to be Permian, so far as can be determined by observation in Brazil.

The fossil conifers collected by me in the region of the bitu-

minous shales of Codó, and the occurrence of the same fossils at the Barra do Corda,* where the same beds outcrop, support this theory. Our preliminary studies lead us to conclude that the bituminous shales of Codó, of the Barra do Corda and of Manoel Alves in the Tocantins lowlands are to be correlated and represent the same Permian horizon throughout northern Brazil. If these assumptions prove to be correct, the bituminous shale is a base of reference in north Brazil as important as the Iraty shale in the south.

If the information given me can be depended upon, the shales crop out also in the interior of Piauhy on the flanks of the plateaus that drain toward the Parnahyba between the municipalities of Floriano and Therezina. These statements can only be verified by later studies.

When I went up the Itapicurú, I observed from the steamer, at Manso da Marianna, a big escarpment on the right bank of the river where I thought I could recognize an unconformity. The banks of the river are of sandy and clayey rocks, always red and ashen gray but free from alluvial sand. These sediments are horizontal, but in the river bank at Manso the lower bed seems to show an erosion surface at the contact with the upper one. A detailed examination would perhaps permit the recognition there of the contact of the Cretaceous or Tertiary beds of the coast with the pre-Cretaceous or Permian of the interior.

Independent of these observations on the banks of the Itapicurú at Manso, we know that, in accordance with facts stated above, and the occurrence of fossil dicotyledons with *Psaronius* in the Parnahyba valley, the Cretaceous rests directly on the Permian in the eastern part of Maranhão. The occurrence in the region described of bituminous shales at the base of the Cretaceous of northern Brazil (Araripe) renders possible the theory of two bituminous formations, one belonging to the lower Cretaceous, the other to the Permian. This plausible hypothesis introduces further doubt in regard to any method other than paleontologic for the determination of the ages of these sediments.

Geographical Limits of the Permian and Triassic.

From the notes of my assistant, Mr. Baumann, we have seen that we can safely extend the limits of the Permian from the south of Maranhão to Porto Nacional in Goyaz. In the upper Parnahyba these sediments occur at the headwaters of the Balsas.

Through the geological studies of Dr. Roderic Crandall we can now identify with the series of the Parnahyba the greater part of the sediments of Piauhy between Floriano and Picos.

* J. C. Branner, Geologia Elementar, p. 246.

Dr. G. A. Waring and Dr. Manoel Arrojado Lisboa in their trip in the northwest across the Serra Grande, descending into the Poty valley noticed a disturbance of the sediments and the occurrence of diabasic rocks. For this reason they supposed, even before they knew of this work, that the sediments of the channel of the Poty river were pre-Cretaceous.

Thus a great part of the sediments of the state of Piauhy certainly belong to the Parnahyba series, while the Cretaceous area, which has hitherto been considered as embracing almost the whole state, is greatly restricted.

Very likely the sediments of this series, which we know continues to the lowlands of the Tocantins, extends to the mouth of the Araguaya, and probably embraces the slopes of the chapadas where the Gurupy and Guama rivers rise.

In his trip to the Tocantins the author frequently found, above Alcobaça, beds of flints in red sandstones which permit the presumption that sediments of the Mearim series occur in the plateaus of the region.

Conclusion.—It is too early to correlate the sediments of the Maranhão system with those of Santa Catharina.

The lithologic similarity of the sediments of the different series of the north and of the south of Brazil is very notable, especially that of the beds of Pastos-Bons, of the top of the Parnahyba series with those of Estrada Nova, and of the series of Mearim with that of S. Bento.

The author recognizes that they occur with the same aspect in the base of the plateaus of Matto Grosso, in the Aquidauana and Miranda valleys, in the basin of the Paraguay, while the existence in the north of the bituminous shales almost certainly in the upper part of the Permian under conditions that recall the bituminous shales of Iraty in the south is worthy of note.

It is clear that the zone or area of upper Paleozoic sediments in northern and central Brazil is much greater than has been heretofore supposed.

The study of the recognized Permian in Brazil and of its abundant fossils of different types of *Psaronius*, is of great interest and offers a great field for observations.

It would be of still greater interest if the lower Permian series corresponding to the Tubarão series in Santa Catharina could be recognized.

In the channel of the Parnahyba below Nova-York the recognized Permian sediments occur at the horizon of *Psaronius* or in a higher horizon. Also the slopes of the Maranhão plateau which drain toward the lowlands of the Tocantins consist of the same sediment containing these fossil plants.

In the lowlands of the Tocantins, between Carolina and Porte Nacional, the Permian rock encountered is also the sandstone from the same horizon as *Psaronius*.

This seems to indicate that these sediments of the upper Permian outcrop in the states of Maranhão, Piauhy, and Goyaz sufficiently thick and sufficiently flat to permit the excavations of the river valleys in them.

It is important to recognize that the upper Permian sediments with *Psaronius* in the north of Brazil are approximately horizontal from their limits, undoubtedly recognized from the parallel of Campo Maior north of Therezina to the channel of the upper Tocantins in the center of the Brazilian plateau.

In southern Brazil the coal measures are about 150 feet below the Iraty shale, which is the lower limit of the sediments with *Psaronius*, but for the time being we can foretell nothing as to the conditions and occurrence of the lower Permian in the north of Brazil.

North of Campo Maior some wells were dug in the Permian beds, and in one of these a bed of pyritous lignite was found which I myself have not had an opportunity to examine. This indicates the probable presence of older sediments than those of the upper Permian with *Psaronius*.

In Goyaz, in the bed of the Tocantins between Porto Nacional and Carolina, the Archean terrane with lower Paleozoic eruptive outcrops. There it may be possible to recognize the basal sediments of the Permian in northern Brazil.

It is now clear that the continent of Gondowana embraced a large part of both northern and southern Brazil, nearly from the Atlantic directly below the mouth of the Amazon, to the boundary with Uruguay and even beyond it.

In 1909 I had occasion to call the attention of the Geological Service of Brazil to the occurrence of certain fossil plants found by the Brazilian engineer Nascimento Moura in a well dug near Aracy, in the semi-arid part of the state of Bahia. In April, 1912, I sent specimens of these plants to Professor R. Zeiller of Paris, who recognized the genus *Alethopteris*, an upper Carboniferous or Permian form. Later, David White made a study of specimens of these plants collected at the same place by Dr. J. C. Branner in 1911 and fully confirmed the determination of Zeiller. He named the species *Alethopteris branneri*.* It is thus clear, that the Permian covers not only parts of Goyaz, but of Bahia between the Rio S. Francisco and the coast.

Recalling trips made in the upper Rio S. Francisco regions in Minas, in the Rio Paracatú basin, and in the basins of upper tributaries of the S. Francisco, I think it probable that certain sedimentary beds of that region may hereafter also be found to be of Permian age.

Rio de Janeiro, Brazil.

* This Journal, xxxv, 615, June, 1913.

ART. XXXVII.—*A Finger Lake Bed in Ashland and Wayne Counties, Ohio, with Tilted Shore Lines;** by GEORGE D. HUBBARD.

Descriptive.

IN 1907 I passed through the region under consideration and examined the evidence pointing to an abandoned lake plain and accompanying features. A description of this one with three others, all called Finger Lakes, was published in 1908,† but at that time no levels other than rough barometer determinations were made and the warping of shorelines was not then discovered. During the past two summers, further and more exact work has been possible, hence the present writing to set forth the results.

Previous Work by Others.—In 1878 M. C. Read‡ refers to this same lake plain and its swampy condition, and recognizes it as connected with the moraine and drift deposits interfering with former drainage. He also speaks of the "sand and gravel ridges lying along the preglacial valley sides" but does not even suggest that these ridges may be beaches. Of course with no precise levels and bench marks to start from, he did not level up the beaches and discern their loss of horizontality.

Claypole must have come very close to this lake plain, for in his "Lake Age in Ohio"§ he describes Lake Ohio approaching within 4–5 miles of the southern end of this bed, and a marginal or foot lake lying entirely northward and extending within perhaps one mile of the other extremity of it. He does not intimate that a lake lay where the accompanying map depicts this one: nor can the present author find either of Claypole's lake beds.

Leverett, in his voluminous and detailed report on the glacial features of the Erie and Ohio Basins,‖ points out the gravels and sands at the upper end of the lake and calls them outwash terraces built in front of the Wabash moraine. But he makes no reference to a lake plain, as such, south of the terraces. A recent publication by A. Dachnowski¶ mentions a peaty deposit about one mile N.E. of Big Prairie in the abandoned plain of a Finger Lake.

Name and Location.—The name Craigton Lake, from the most important crossroads on the plain, is now given to the

* Presented in abstract to the Ohio Academy of Science, Nov. 29, 1913, and published with permission of the State Geologist.

† This Journal (4), vol. xxv, pp. 239–243, 1908.

‡ Geol. Surv. Ohio, vol. iii, pp. 519–522, 529.

§ E. W. Claypole, Trans. Geol. Soc. Edinb., vol. v, pp. 421–458, 1887.

‖ Frank Leverett, U. S. Geol. Survey, Monograph xli, pp. 565 et seq.

¶ Geol. Surv. of Ohio, 4th ser., Bull. 16, p. 134. Peat Deposits of Ohio. 1912.

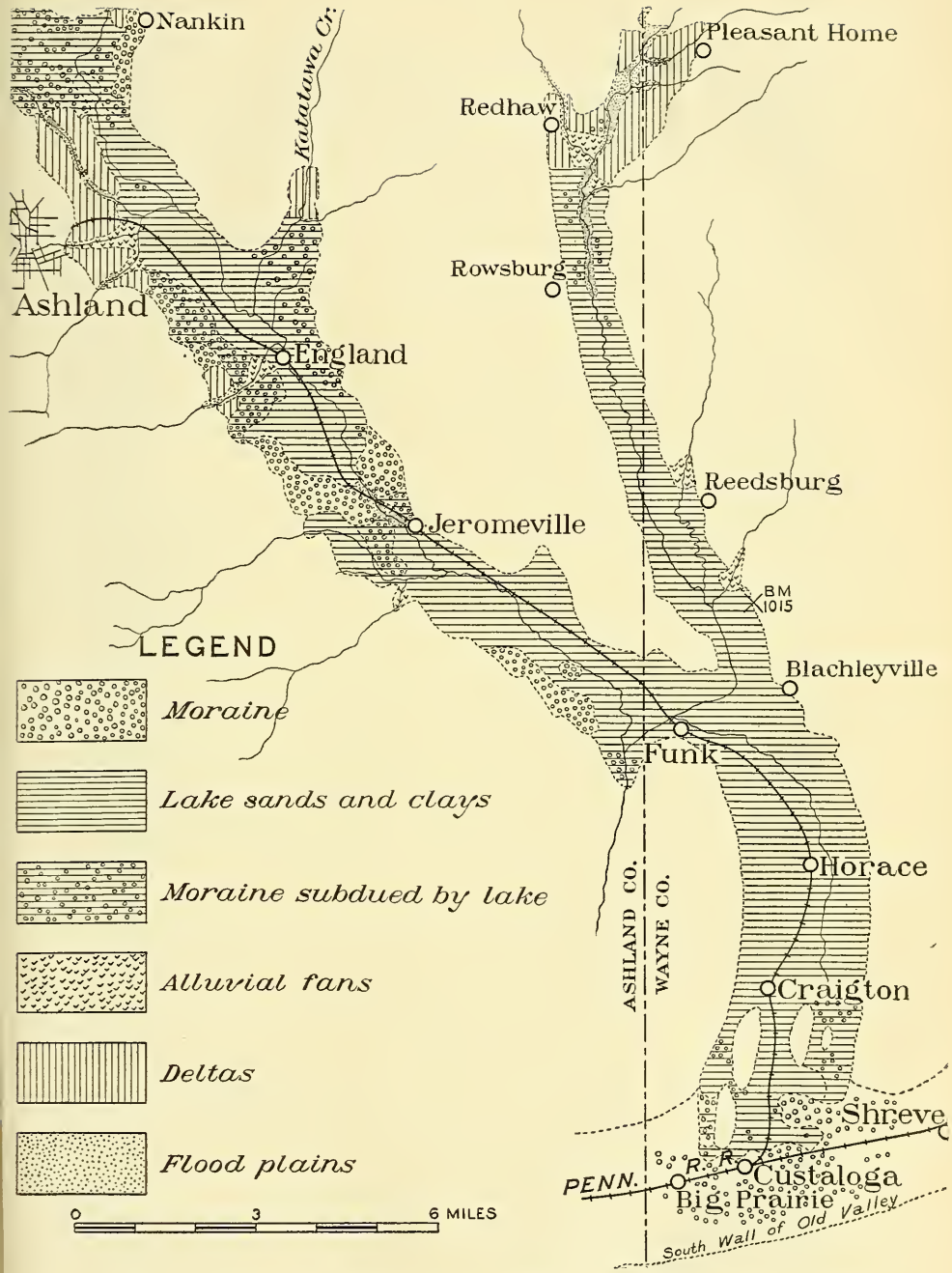


Fig. 1. Outlines and physiographic relations of lake features where Craigton Lake, O., lay in early post-glacial time.

body of water which formerly occupied the lake plain and constructed the beach features. The water lay in very mature, pre-glacial, rock, valleys converging southward and uniting at Funk. The lake had two northern arms; the western lying northwestward toward Ashland; the eastern nearly northward toward West Salem, a town some three miles beyond the limits of the map (fig. 1). These arms united where the pre-glacial valleys joined. The southern extension of the lake was the broadest portion. This and the eastern arm constituted together a lake having a length of 18–19 miles, and a width varying from three-quarters of a mile to more than two miles. Several large rock islands and some moraine hills rose above the water in the southern half. This southern extremity lay among the morainic hills and against the rock walls of the great, mature, pre-glacial valley in the vicinity of Custaloga, at the junction of the Lorain, Ashland and Southern railroad with the Pennsylvania line.

Deltas and Beaches.—That such a lake really existed is abundantly attested by the constructional work it left behind. The shoreline can be traced nearly continuously along the eastern side of the valley from Custaloga northward past Blachleyville and Reedsburg, to Pleasant Home. The western shoreline can be traced northward past Craigton to Funk; and here it bears off northwestward, following the western arm to points a mile or so east of Ashland and even farther.

The beaches are usually sandy, occasionally pebbly; stratification is rarely discernible but may once have been more generally present. In general not only structure and material but even form are present to establish the identity. A little terrace is the customary manifestation (rarely a cliff above it): and below the terrace top a slope, becoming gentler downward, descends to the plain level. On this slope the sands of the beach grade into finer and finer material until the clays and imperfect drainage conditions are reached. In some places where either the conditions for construction were unfavorable, or those for removal were good, no beach could be found. A number of little cliffs, now much weathered, occur on the drift hillsides near the southern end.

Lake clays are exposed in the bottom of the plain in a number of places, fine and very pure in the central part, more sandy toward the north end, and more heterogeneous toward the southern end. Much beside clays lies in the valleys below the lake plain. The upper parts of the valley walls now exposed rise about 1 foot in 20 or between 2° and 3°. If the walls continue below the present lake plain level at the same angle until they meet, the rock valleys are filled 50–100 feet deep in the narrower northern part and 200 feet in the broader

part near Funk and southward. Wells are shallow all through the lake plain. Only one was found that reached rock and in this the depth to rock could not be ascertained. Material passed through was peaty at the top, clays and sands below, with hard-pan (drift) and gravel on the rock. This material is said to be very thick.

Rather well-marked and extensive deltas occur at the upper ends of the lake bed wherever streams flowed into the lake. These are now much dissected by their builders because the lake has disappeared and given them a lower local base-level. These are discussed more fully in the next two sections.

Upper Ashland Arm Probably Separated by Moraine.—Considerable areas of delta sands occur east and northeast of Ashland where Town Run and Long Creek entered the lake. A number of moraine hummocks 3–4 miles northeast of Ashland and beyond the delta deposits have been worked over by water, with the sorting out and removal to lower levels, of the clays. These hummocks, now capped with sands and gravel too coarse to have been washed off, still rise generally above 1000 feet, and occasionally above 1020 feet. Orange Creek also built a small delta into this northwestern extremity of the lake just west of the present site of Nankin. Its surface is about 1010 feet high. Katotawa Creek also built a small delta into the lake two to three miles north of England, bringing its materials from the thick drift deposits of the Wabash moraine. These deltaic deposits and forms in the Ashland arm of the lake are 20 to 30 feet lower than those on the West Salem arm, and this fact, together with the presence of the big moraine loops across the valley at Jeromeville and England, strongly suggests that the waters from the former town northwestward were separate, through most of the lake history, from those in the main body. A youthful valley 50–60 feet deep through the morainic loop at Jeromeville now connects the upper portion with the lower or main basin. The upper portion was shallower and more cut up by moraines and irregularities of shoreline, hence its shore features are less distinct and poorly developed. Possibly its overflow was at one time northwestward to the Vermillion River, but this seems doubtful and certainly indeterminate at present.

The Eastern Arm.—In the eastern or West Salem arm extensive deltas were built by streams flowing directly from the edge of the ice and heavily laden with waste. They are of typical delta structure with foreset and topset beds now visible in exposures made by excavations for commercial gravel. Here, as in the Ashland arm, the deltas seem to have been built out into the water over moraine topography and among moraine islands, for beneath the stratified deltaic material the unstratified drift was seen in several places.

The Main Lake Bed, Depth of Water and Outlet.—At many points streams in post-lacustrine time have cut channels through delta and beach deposits and have built pretty alluvial fans in their valley mouths and out over adjacent parts of the lake plain.

Hundreds of springs issue from the rock hillsides and send their clear wholesome waters down the slopes to the lake plain. These springs not only determine the locations of many farm houses and roadside watering troughs, but keep considerable tracts of the plain in a marshy, miry, condition wholly unfit for agriculture. A dredge ditch has been dug through much of the length of the lake plain. Another close to each side, to catch and conduct away this spring water when it first gets down to the level of the plain, is still necessary to reclaim fully the rich lake plain.

In the author's previous paper* referred to above, it was stated, through some typographical error, that the "level of the beaches near Funk and Blachleyville was 765 ft." instead of 965 as determined by the barometer from the U. S. G. S. levels. The lake in this vicinity could not have been less than 50 feet deep, but was shallower in both arms and probably also toward the southern end.

The outlet was by Lake Fork of Mohican River at the junction of the northern arms of the lake through a valley, still narrow and steep-sided, and probably opened up in some interglacial stage,† over the divide between Funk on the shoreline and Lakeville station on the Pennsylvania railroad.

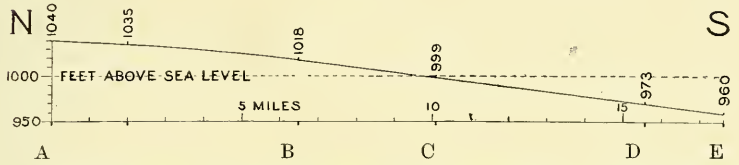
At present the lake plain is drained, though as yet somewhat imperfectly, by three streams, Jerome Fork in the Ashland arm, Muddy Fork in the West Salem arm, and a small dredged stream in the southern body; three streams which unite near Funk to form Lake Fork, both the ancient and the present outlet.

Attitude of Shore Lines at Present.—Examination of the shorelines led to the belief that they were not as constructed. To make certain just what the condition is, a Y-level was used working out from precise levels and bench-marks of the U. S. Geological Survey. By this means it was found that the beach lines are far from horizontal to-day. The accompanying section (fig. 2) exhibits the results graphically. Along the eastern arm and main body from Pleasant Home to Custaloga the altitude was determined at several points. The delta surfaces at Pleasant Home and Redhaw were found to be over 1040 feet; and the shorelines seem to grade down from these surfaces to 1020 at Rowsburg; 1015 about 1½ miles north of the

* This Journal (4), vol. xxv, p. 243, 1908.
† Ohio Naturalist, vol. viii, pp. 349–355, 1908.

latitude of Reedsburg; 998–1000 feet on the road crossing the valley about half way between Reedsburg and Blachleyville; 973 at the Craigton road and 960 where the Lorain, Ashland, and Southern railroad crosses the wagon road one-eighth mile north of Custaloga. Little wave-cut cliffs in the hills of this southern boundary together with beach phenomena make the determination here rather certain. No wave work could be located in the vicinity above the 960 foot level but there was

FIG. 2.



A, Pleasant Home. B, 1¾ miles N.W. of Reedsburg. C, Near Bench Mark, 1½ miles N. of Blachleyville. D, Near Craigton. E, Near Custaloga.

FIG. 2. Section along an approximately north-and-south line following shoreline features of main body and eastern arm of Craigton Lake, O.

plenty below. This point is as certain as that there was wave work and delta building recorded at levels above 1040 at the north end. Allowing five or six feet for fan deposits or outwash on top of the delta at the north end, we still have an altitude of 1035 here or 75 feet above the shore features at the southern end. This means a tilting upward relatively at the north with reference to the southern end of 75 feet in between 18 and 19 miles, or 4 feet to the mile. See section.

Interpretations and Correlations.

The post-glacial tilting of the shorelines of the precursors of our Great Lakes has long been recognized. Very little evidence has been found of tilting south of the borders of our present lakes. The long east-and-west abandoned beaches across Ohio show almost no tilting, but lines running more nearly north and south are appreciably displaced. The evidence presented above carries actual tilting 50 miles south of the most southern part of Lake Erie, itself the most southern lake. Furthermore the rate of tilting is greater in this case than that observed on many of the abandoned beaches farther north.

Goldthwait,* who has worked extensively on abandoned beaches to establish the amount and kind of warping that may

*J. W. Goldthwait, Geol. Soc. Am., Bull. vol. xxi, pp. 227–248, 1910.

have taken place, shows that the Algonquin beach is not tilted south of a line through the middle of Lake Michigan and Niagara Falls. In the same paper he shows that the older Iroquois beaches are tilted more than the Algonquin in the same latitudes and that the tilting extends further southward for the Iroquois beach. He shows that the tilting is greatest farther north and decreases southward, but he is unable to locate any southern limit for the tilting.

That the existence of Craigton Lake began earlier than that of any of those preceding, even Lake Erie, is easy to believe because of its location with reference to the retreating ice. It was not an ice-front lake but several miles south of the divide and twenty-five miles from the Maumee beach. Its site would be uncovered even before that of Lake Maumee. That tilting in the Lake region began early is also shown by the fact that Craigton Lake shorelines are tilted more than beaches such as those of the Algonquin and Iroquois water planes. The warping in Craigton Lake lines amounts to 4 feet in a mile and is quite uniform for the eighteen miles of length. It may be a little steeper in the last two or three miles at the north end but probably is not. The apparent increase in rate is more likely due to aggradation with glacial outwash or to the building of a fan on the Pleasant Home delta.

Craigton not only began, but probably completed its history as a lake before the tilting occurred; a considerable part of its tilting must have occurred before the Iroquois beaches were tilted and all of it before the Algonquin was tilted, because in the first place its tilting is greater than that of Iroquois; and in the second, Algonquin tilting did not proceed so far south. Had the water remained in Craigton during the tilting, it must have spilled over southward. There can be found no evidence of static water work on the hills above the recorded beach levels at the southern end. If water stood higher here, then many tracts, low between moraine hills but higher than 960 feet, should have been under water and should attest that fact by sorted drift, lake clays, and possibly by black earth deposits of palustrial origin. Nothing of the sort can be found.

Because the outlet was in the middle portion of the lake the southern part would not be drained by the tilting. Drainage possibly fairly well established would be interfered with; swampy conditions would develop and will persist until more perfect drainage is attained. Black, peaty earth, very abundant in southern part, confirms the belief that this end of the lake was long swampy. In fact artificial ditching has but recently put it into agricultural condition. Hundreds of acres of onions are now grown on the black flats that are sufficiently drained. Water does not stand anywhere on the plain but swampy conditions are not entirely removed.

Oberlin College, Oberlin, Ohio.

ART. XXXVIII.—*Remnants of an Old Graded Upland on the Presidential Range of the White Mountains;* by JAMES WALTER GOLDTHWAIT.

THE Presidential Range lies sixty-five miles inland from the sea, in north-central New Hampshire. It extends in a northeast-southwest direction for a distance of eighteen miles, with a width of about three miles. On it are eight principal summits or "peaks," of which Mount Washington is considerably the highest, with an altitude of 6290 feet. From this range streams flow off in all directions, reaching the sea through four of the largest rivers of New England,—the Connecticut, Merrimac, Saco, and Androscoggin. In respect to drainage lines, therefore, this district is extremely remote.

In form, the mountains of the Presidential Range present two contrasted sets of slopes: subdued, well-graded slopes above, and bold, precipitous slopes below. The former appear to be due to long continued sub-aërial wasting of an early cycle; the latter, to deep and extensive stream dissection during a later cycle, accentuated by local glaciation of the ravine heads. Subordinate to these features, but modifying them in detail are index forms of regional glaciation, of a later date than the stream erosion and local glaciation.

On all sides of the range lower ranges and summits exhibit a surface so irregular, from whatever altitude it is viewed, that one fails to see in the landscape any satisfactory trace of an uplifted peneplain such as Davis has described in southern New England. The exposure everywhere of contorted metamorphic rocks and plutonics bears abundant evidence, however, that the interior of New England, like the better known outer portion, has been stripped of thousands of feet of its original rock structure. The lofty mountains of the Paleozoic and Mesozoic landscape have been worn down to an irregular upland of moderate relief. No organized effort has yet been made to correlate the physiographic features of the White Mountains with those of southern New England. The peneplain which extends over Connecticut, Rhode Island, and Massachusetts has never been followed far into New Hampshire. This neglect by the physiographer seems strange, in view of the fact that the White Mountains have become widely known as a vacation resort for the tramper, camper, and mountaineer.

Professor Davis, in his description of the peneplain of southern New England,* says that on "passing northward into

*W. M. Davis: The Physical Geography of Southern New England. National Geographic Monographs, No. 5, p. 269-304, 1895.

FIG. 1.

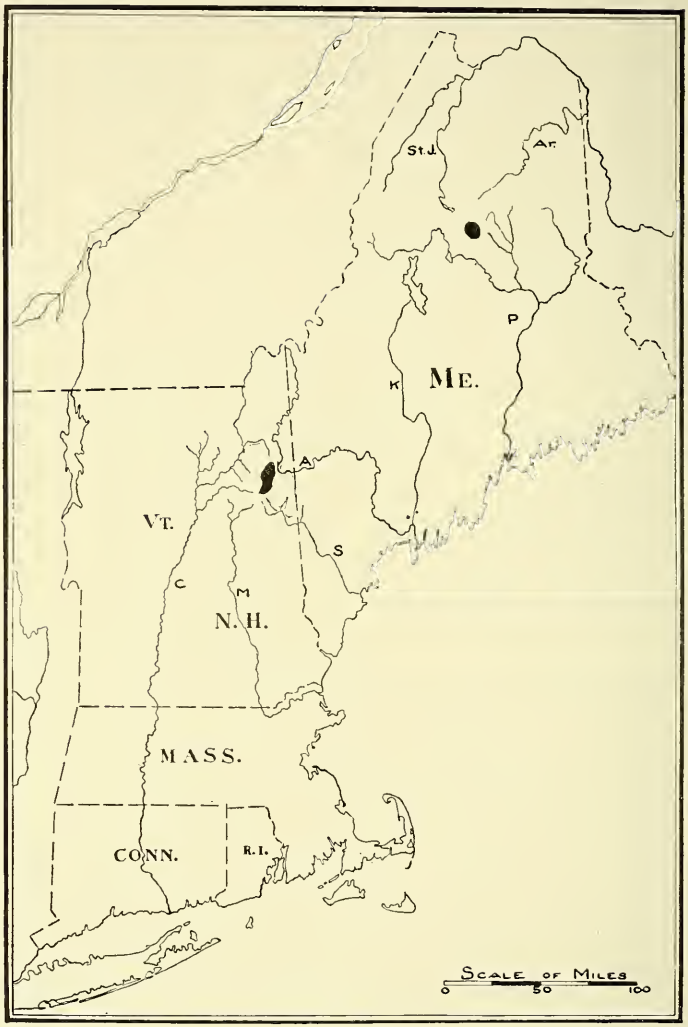


FIG. 1. Outline map of the New England States, showing in black the position of the Presidential Range in New Hampshire and Mount Ktaadn in Maine, and the large rivers which rise near them. These rivers are : C Connecticut, M Merrimac, S Saco, A Androscoggin, K Kennebec, P Penobscott, Ar Aroostook, and St J St. John.

Vermont, New Hampshire and Maine monadnocks are common. The White Mountains seem to be only a cluster of unconsumed remnants . . . but in spite of the nearness of these northern states they have not been explored with the upland peneplain and the monadnocks in mind. No definite statement can at present be given to the altitude of the upland in northern New England or as to the degree of perfection that it attained."* Again in 1899, Professor Davis writes: "The White Mountains have been in my mind tentatively classed as a group of monadnocks; they do not, as far as I have seen them in brief excursions, stand upon any distinct basement comparable to that of the uplands of New England further south. . . . The ruggedness of the district is generally so great that it is quite possible that the peneplain explanation does not apply to the greater part of the area. Little wonder that an observer whose attention is given to this mountainous district under the impression *that its mountain tops represent the remnants of a peneplain* should come to discredit such an explanation."†

It is my purpose in this paper to point out the possibility that the summit portion of the Presidential Range, contrary to the implication by Professor Davis in the foregoing quotation, may be a remnant of that ancient graded landscape which, according to his theory of baseleveling, consisted in the more southerly portion of New England in a rather fully developed peneplain. In short, it will be suggested that the subdued cones of Washington, Jefferson, Adams, and the other summits of this range are low monadnocks surmounting a peneplain whose only surviving fragments, in this district, are the upland "lawns" and "Alpine pastures" that lie along the crest of the range.

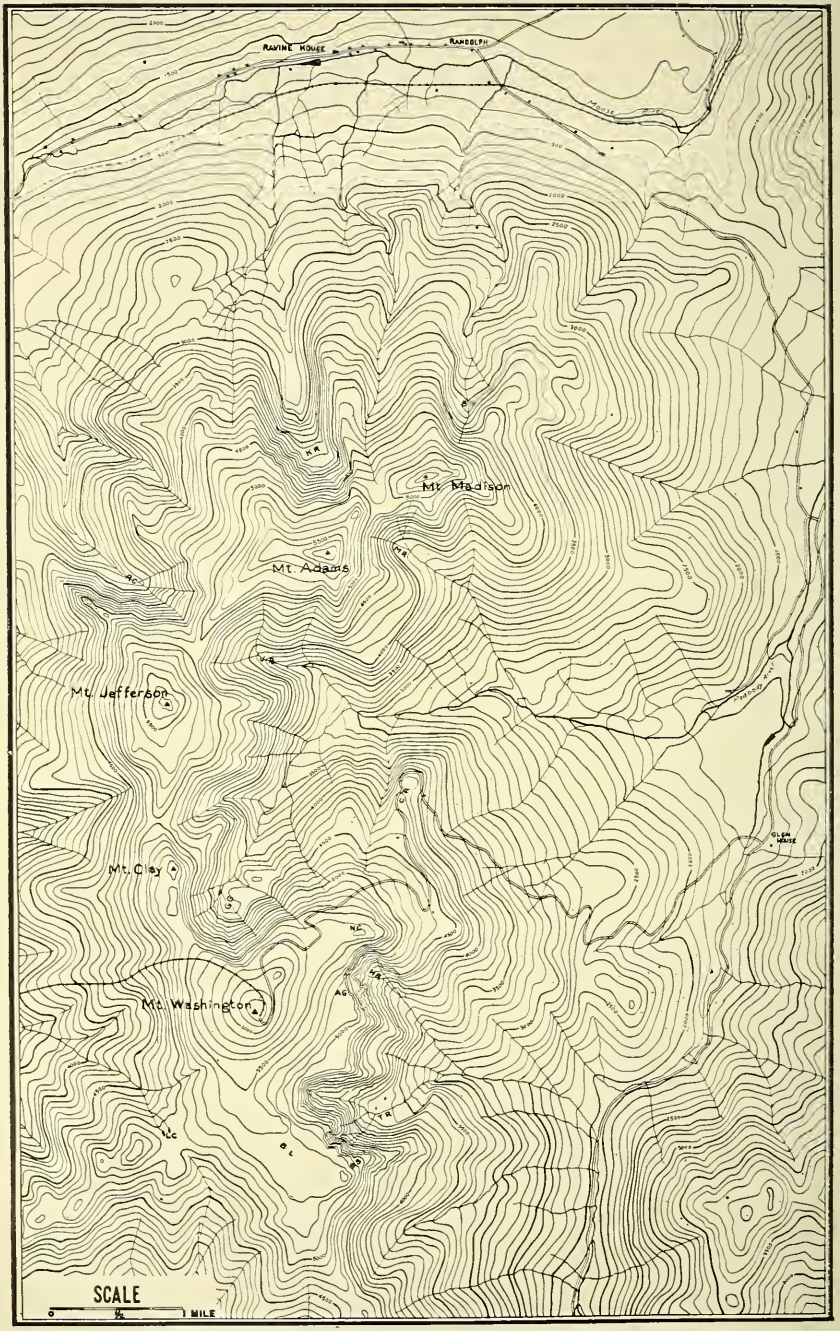
The Upland "Lawns."

As one ascends Mount Washington from the southeast he is impressed by the extraordinary flat area which he reaches about 1000 feet below the summit. This great "lawn" extends along the top of the range from the upper end of Boott's Spur for over a mile before reaching the foot of the cone of Washington. Its width is fully half a mile and its rise so slight and so gradual that in contrast to the precipitous headwalls of the ravines below and the rather steep sides of the cone above the lawn appears smooth and level. It is perhaps the most striking feature encountered because the

* Op. cit. p. 283.

† W. M. Davis: The Peneplain, American Geologist, vol. xxiii, pp. 209-210, 1899. The italics are not in the original.

FIG. 2.


RAWINE HOUSE
RANDOLPH
Mt. Madison
Mt. Adams
Mt. Jefferson
Mt. Clay
Mt. Washington
GLEN HOUSE
SCALE
1 MILE

least expected. The earliest printed description of the White Mountains, by Josselyn, referring to the Presidential Range, says that "upon the top of the highest of these mountains is a large level or plain . . . whereon nothing grows but moss. At the further end of this plain is another hill . . . to outward appearance a rude heap of massive stones piled one upon another."* Similar descriptions of the flat upland surface, not only here at Bigelow's Lawn but at other points on the top of the range, are found in the writings of later explorers and visitors, including particularly Starr King, the author of the classic volume on "The White Hills."† In his "Geology of New Hampshire," Professor C. H. Hitchcock‡ repeatedly draws attention to the importance of this smooth highland. "On descending from the top of Mount Washington to the Lake of the Clouds," he says, "the explorer will find a very flat region, running easterly into Boott's Spur and northerly along the east side of Washington. . . . The abyss in front is Tuckerman's Ravine, with tributary scallopings on the northwest sides. The erosion has been vertical, just as in a gorge worn out of a level plain. . . . Oakes Gulf, Huntington's Ravine [and the Great Gulf] are other deep gorges excavated out of this plateau, . . . This table land is less than ten miles in length and somewhat over 5000 feet in elevation."§ Several illustrations, some of them copied from Starr King's "White Hills," and others, as for instance, the heliograph opposite page 618, which are new productions, show the smoothly graded forms of the cones and bordering lawns, in contrast to the great re-entrant headwalls of the cirques or "ravines."

Although these upland lawns or pastures are most conspicuous on the south and east sides of Mount Washington, they can be traced all along the line of the Northern Peaks. From Boott's Spur the broad plateau known as Bigelow's lawn finds continuation between the 5000 and 5500-foot contours around the base of the great cone in a wide shelf that is known locally

* John Josselyn, New England varieties discovered, 1672.

† T. S. King: The White Hills.

‡ C. H. Hitchcock: Geology of New Hampshire. Final report of the State Geological Survey of New Hampshire, 3 vols., Concord, 1874-1878.

§ Op. cit., vol. i, pp. 609-610.

FIG. 2. Contour map of the Northern Peaks of the Presidential Range of the White Mountains. Copied with additions and slight alterations from the map published by the Appalachian Mountain Club.

R C, Ravine of the Castles; K R, King's Ravine; B B, Bumpus Basin; M R, Madison Ravine; J R, Jefferson Ravine; G G, Great Gulf; C R, Chandler Ridge; N C, Nelson's Crag; A G, Alpine Garden; H R, Huntington's Ravine; T R, Tuckerman's Ravine; B S, Boott Spur; B L, Bigelow's Lawn; L C, Lake of the Clouds.

as the "Alpine Garden." The semicircular headwalls of Tuckerman's and Huntington's Ravines have been cut far back into this portion of the lawn; but its gentle eastward slope is sufficiently well preserved to convey the impression of a nearly level upland which was once of great extent. See map (figure 2), and photograph (figure 3). Around and beyond Nelson's Crag, which rises as a low monadnock above the lawn, the graded slope continues, passing down the crest

Fig. 3.

Fig. 3. View on the "Alpine Garden" looking over the headwall of Huntington's Ravine. By E. H. Lorenz.

of Chandler Ridge for a mile and a half to an abrupt shoulder at 4000 feet, near the Halfway House. Here the end of the spur was trimmed away by glaciation during the excavation of the Great Gulf, the greatest of the White Mountain cirques. The carriage road takes advantage of this ancient graded surface to accomplish the last half of the eight-mile ascent from the Glen to the summit of Mount Washington. On the north side of Mount Washington the head of the Great Gulf cirque was eaten back beyond the limit of the lawn and up into the slope of the cone itself. On the northeast side of Mount Clay, however, another flat-topped spur appears

between two amphitheatres of the Great Gulf glacier, which is preserved down to the 4500-foot contour. Southeast and east of Mount Jefferson is a longer remnant of the old upland surface. At Monticello Lawn the presence of a considerable patch of bowlderless ground in the mantle of glacial drift prompted someone several years ago to put out a croquet set, where visitors might play the game at the very top of the range. This lawn runs down the crests of the two

FIG. 4.

FIG. 4. View of the graded cone and "knees" of Mount Jefferson, seen across the Great Gulf from Mount Washington. By E. H. Lorenz.

"Knees" of Jefferson as far as the 4500-foot contour, beyond which, as in the case of Chandler Ridge, the ends of the spurs have been trimmed off by the Great Gulf glacier, leaving two large triangular facets (see figure 4). Around Mount Adams and its subsidiary summits the sides of the cones flatten perceptibly into graded lawns like those already described. Southeast of the peak of Adams, in particular, the graded surface reaches down to a broad shelf that overlooks the Great Gulf directly opposite to Chandler Ridge. The two remnants of the old graded slope agree perfectly in altitude, standing at 4000 feet.

Throughout the area just described the lawns are covered with loose rocks and glacial bowlder clay. Although at first glance one would probably say that this is post-glacial talus, cracked off from the exposed ledges by winter frosts and pushed slowly down the slopes, the disposition of the fragments, and particularly the lines of white quartz blocks which may be seen trailing in the direction of motion of the continental ice-sheet, not straight down hill but obliquely down or even up hill, from striated parent ledges, indicate rather that this sheet of loose rock is not now on its way down hill, but rests exactly where the ice sheet dropped it. In the steep-walled ravines there has of course been considerable sliding of this debris in post-glacial time; but on the gentler slopes of lawns and cones generally it seems to record little if any recent movement. It is bowlder clay in the first stages of production, which for want of a specific name we may call "block till."

While the lawns are thus virtually continuous along the line of the northern peaks from Boott's Spur to Mount Adams, the greater part of the crest of the range in this distance is occupied by the cones themselves. A brief description of these may now be given.

The Cones.—Washington, the highest of the cones by nearly 500 feet, is also the roundest. While it is somewhat steeper on the southeast side, the asymmetry is so slight that the mountain appears in profile as a rounded dome from every side. As already mentioned, however, the Great Gulf has been cut back into the north side of the cone fully half way to its summit. This extraordinary foreground, as well as the similar cirque re-entrants of Huntington's and Tuckerman's Ravines on the east side, lend variety to the appearance of the mountain as seen at close range from different viewpoints. The surface of the cone is covered even to its top with block till like that of the lower slopes and lawns, with which are associated peculiar streaks and patches of ordinary glacial bowlder clay. The verdure of these patches, especially where they are well watered by springs so as to support a luxuriant growth of Alpine flowers, greatly relieves the cold gray landscape of the rocks. Here and there exposures of bed rock appear, especially on the southeast side of the mountain, where low cliffs may be seen; but these have in most places been so much cracked and loosened that the distinction between them and the scattered blocks is not easy to see. To some extent the ledges, particularly at the summit, show the flattish, smoothed crowns characteristic of glaciation, but there are no distinct striæ or grooves there. The presence of both bowlder clay and erratic bowlders on and around the summit proves, as Professor Hitchcock discovered in 1875, that the cone was completely covered for a

time at least by the great ice sheet. The bowlder clay is much looser and much more largely composed of fragments of the local rock than that at lower altitudes, suggesting that the summit of this highest mountain of New England was not very long nor very deeply covered by the ice sheet.

Mounts Jefferson and Adams, whose altitudes are approximately 5800 feet, represent a rather different type of cone. Their summits are not rounded like the dome of Washington, but distinctly angular; and their eastern sides are much more precipitous than their western ones. On Mount Jefferson this asymmetry is very pronounced, as those have noticed who have approached the mountain from the northeast by way of the Gulfside or Randolph Trails. It seems at first sight as if the lack of symmetry were due primarily to the regional glaciation, which was here in a southeastward direction. The detachment of loosened blocks and talus on the lee side of these high cones would have left cliffs where ledges do occur, while the removal of talus and newly quarried blocks from ascending slopes on the northwest sides would naturally be slow and imperfect. It is not clear, however, how the ice sheet, passing over these cones from northwest to southeast, could steepen their southeast sides so much and at the same time fail to wear down to rounded outlines their summits. The form of the mountains differs from that of typical roches moutonnées chiefly in this angularity of their summits. The argument against regional glaciation as the controlling factor in the form of the cones finds further support in the symmetry of the sharpest and steepest of the peaks, Mount Madison, which, let it be noticed, is also the lowest, and hence the one which must have been most deeply covered by ice. Inasmuch as this peak is 900 feet lower than the top of Mount Washington, it can hardly have been buried by less than 1000 feet of ice, yet its symmetry is nearly perfect and its sharpness highly conspicuous. We must conclude, therefore, that the ice sheet has had little influence on the shape of these cones. They may be regarded rather as products of subaërial wasting.

The Cols.—In the cols between the peaks the evidences of severe glaciation are clear. Ledges at the "parapet" southwest of Mt. Madison, and others just north of the Gulfside shelter east of Mt. Jefferson, particularly, exhibit beautifully rounded northwest sides and ragged southeast faces. Among them are quartz veins whose polished surfaces bear distinct hair-like striæ of the southeastward ice flow. Since these points are only a little below the 5000-foot contour, it is clear that the more severe scrubbing of the ledges in them than of those on the summits of cones like Madison is due not so much to a greater thickness of ice as it is to the concentration of flow

where the ice crowded through the saddles. In the case of the Adams-Madison col, at least, the passage of the ice appears to have scoured the crest of the range into a characteristic hyperbola.

The Ravines.—It has been stated that the cones and lawns terminate sharply at the brink of steep walled ravines. This feature is to be seen in the photographs (figs. 3 and 4) and the map (fig. 2). Since an understanding of the ravines is necessary to a proper conception of the upland, attention may now be turned to them.

Until recently the White Mountain "ravines" have been generally regarded as the products of torrent sculpture, aided by frost and landslides.* It is plain, however, to one familiar with the origin of mountain forms that these great bowl-shaped depressions or "mountain colosseums," as Starr King graphically called them, are glacial cirques. That they are extraordinary, to say the least, was appreciated by those who early gave them the names of "gulfs," "basins" and "ravines." Their glacial origin, however, seems to have been overlooked.† Around the five northern peaks there are no less than eight of these cirques. They lie on all sides of the range except possibly the southwest, and trend in nearly every direction. In size they range from the Great Gulf, whose crescentic headwall is 1500 feet high and whose length, measured along the axis of the trough, is about three miles to the little bowl-shaped Bumpus Basin, with hardly one-third these dimensions. Some of the cirques like King's Ravine are isolated; others, like Jefferson Ravine and the Great Gulf, unite as tributaries to form a single great trough. In all the headwalls are precipitous and the rims well-defined.

In view of this sharpness of form of the cirques, one is surprised to find that local moraines at the mouths are wholly absent. Even the debris near the headwalls, far back within the ravines, is not so disposed as to demonstrate by any means the recent occupancy of the cirques by valley glaciers. In fact, the presence in King's Ravine of bowlder clay carried southeastward by the ice sheet far up into the cirque, and now lying undisturbed on its floor, where local morainic ridges ought to appear had local glaciers become re-established in the cirques at the close of the ice age, seems to require that the carving of the cirques took place before and not after the last epoch of regional glaciation. If any local glaciers whatever survived the ice sheet in the White Mountain ravines they must have

* C. H. Hitchcock, op. cit., vol. i, p. 623.

† Professor D. W. Johnson tells me that for several years he has cited the White Mountain ravines as examples of cirques to students in his class, basing this opinion upon the contour maps of the U. S. Geological Survey.

been rudimentary in comparison to the cirques which sheltered them, for the only heaps of locally derived rock debris lie close to the foot of the headwalls. It is, indeed, doubtful whether such rock heaps are not in every case avalanche deposits and rock falls similar to those described by Howe in the San Juan Mountains.*

Slight alterations of the cirque form by regional glaciation may be seen in certain details of slope. Near the top of the headwall of the Ravine of the Castles, for instance, the jointed ledges were heavily scraped by the ascending ice, developing distinct "roches moutonnées" which *face up hill*, and are closely followed, on the top of the Jefferson-Adams col, by glaciated knobs which face out over the head of Jefferson Ravine. Although the Ravine of the Castles and King's Ravine, which lie nearly parallel to the southeastward line of movement of the ice sheet, are symmetrical in cross section, the Great Gulf, which lay athwart the southeastward current, exhibits a steep wall on its left or northwest side and an exceptionally gradual slope on its right or southeast side, on which thousands of blocks lie scattered as if caught there in a pocket. Obviously there has been some rounding off of the rims of these cirques, where they were most fully exposed to the southeastward thrust of the ice sheet, and some concealment of their bowl-shaped floors by deposits of ground moraine. The greatest damage to their form as cirques, however, appears to have come from rock falls, avalanches, and more regular slides, during the post-glacial epoch, especially at the beginning, when the melting away of the ice from oversteepened and loosened cirque walls caused huge masses to fall or slip to the ground. The effect of these avalanches and slides has been to tear away the rims and to fill up the floors of the ravines, somewhat obscuring their cirque form. Kame ridges and irregular hummocks, and near the upper ends of the cirques moraine-like heaps of great blocks complete the jumble of waste which has accumulated below the cirque walls since the ice age.

Alternative hypotheses to account for the lawns.—The contrast between the smooth lawns with their gentle grades and the bold slopes and cliffs of the flank of the range is strong enough to demand explanation. It has been pointed out that where the graded upland surface passes farthest down along the crests of spurs, it seems to flatten out near the 4000-foot contour. It does not require much imagination to fancy this graded slope blending with wide lowland surfaces at about this altitude, even though no traces of such lowland surfaces now remain. In short, one is inclined to look favorably upon the

*Ernest Howe: Landslides in the San Juan Mountains, Colorado, U. S. Geological Survey, Professional Paper No. 67, 1909.

theory that the old graded slopes are the slopes of residual mountains which grouped themselves around broad intermont lowlands along the frontier of the New England peneplain.

At the same time the evidence is so fragmentary that other possible explanations should be considered. It might be suggested, for instance, that the flatness of the crown of the range is due chiefly to the more rapid reduction of the slopes above the tree line, where frost action and the movement of rock waste are more vigorous than in the forest. This hypothesis, however, has to meet the fact that since the last passage of the ice sheet over the range there has been almost no splitting apart of the roches moutonnées, and surprisingly little movement of the loose rock; and moreover it seems very improbable that the tree line has been at all constant in position through the Pleistocene period. Again, one might look for some structural control of the upland flats,—some dominant system of joints, or some very extensive development of schistosity in planes near the horizontal. The answer to this is simply that while the theory cannot be rejected, the facts thus far observed lend no support to it. Finally, it may be urged that the flattening out of these graded slopes, in their descent, near the 4000-foot contour is not as real as it appears to be; that the original well-graded slopes of the range have been so deeply and so widely scooped away by local glaciers and the resultant spurs have been so much worn, especially at low altitudes, by glaciation during the subsequent regional glaciation that the effect is a false appearance of an uplifted and extensively dissected cluster of low monadnocks.

While suspending judgment in choosing between these interpretations, it is interesting to note that the same gently graded upland topography occurs on the top of Mount Ktaadn in northern Maine. Tarr, in his paper on "the Glaciation of Mount Ktaadn"* thus describes it:

"The main part of the elevated portion of the mountain is occupied by the 'tableland' . . . from which several spurs extend as divides between stream valleys heading on the mountain top. In places this tableland is remarkably level."†

If there is any truth in the theory that the platean-like aspect of the lawns is due to an over-emphasis of the pre-glacial graded slopes by the cirque cutting and general steepening of the lower portions of the flanks of the Presidential Range, it is to be noticed that this theory applies equally well to Mount Ktaadn, whose profound "basins," as Tarr showed, are glacial cirques like the "ravines" and "gulfs" of Mount Washing-

*R. S. Tarr: The Glaciation of Mount Ktaadn, Maine, Bull. Geol. Soc. America, vol. xi, pp. 433–448, 1900.

† Op. cit., p. 440.

ton. It is perhaps of even greater significance, however, that Mount Ktaadn, like Mount Washington, stands at the headwaters of three great river systems, the Penobscot, Aroostook, and the St. John,—to which might fairly be added also the Kennebec, since this river system which now heads in Moosehead Lake, some distance southwest of Ktaadn, probably drained the slopes of the mountain in pre-glacial times. The occurrence of old upland topography in these two typically remote spots among the drainage systems of New England (see fig. 1) raises the question whether we ought not to expect remnants of the New England upland to survive at the extreme headwaters of these great rivers long after all traces of that upland had vanished from the more dissected region occupied by their larger branches and trunks. With this idea in mind it will be interesting to see if similar scraps of graded upland come to light in the Green Mountains and other remote inland places.

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ART. XXXIX.—*The Shawangunk Conglomerate and Associated Beds near High Falls, Ulster County, New York*:* by THOMAS C. BROWN.

IN several recent papers the Shawangunk conglomerate and the overlying shales and sandstones (Longwood shale of New Jersey and High Falls shale and Binnewater sandstone of New York) have been described as continental, flood plain, or torrential deposits.† While employed by the New York City Board of Water Supply during the preliminary surveys and early construction work for the Catskill Aqueduct across the Rondout Valley, the writer had exceptional opportunities to study these beds in numerous diamond drill cores and in the five shafts which penetrated them and exposed the section complete in its natural unweathered condition. Several of the observations made upon them under those conditions do not agree with the published descriptions, nor do some of them conform to the theory of continental origin. It, therefore, seems advisable to publish these observations so that other workers interested in this problem may study the above mentioned papers with these facts before them.

Historical sketch.—The Shawangunk conglomerate of Ulster county and the associated beds of red and green shale lying between this and the limestones and cement beds of the Upper Silurian were recognized and described by Mather in his geology of the First New York District (pp. 353–355). He even gives a detailed section with measurements of the beds at "High Falls on the Rondout in Marbletown, Ulster county," the exact location where the studies for this paper were commenced. Mather did not definitely correlate these beds with their western equivalents. He closed his discussion thus: "The observations made do not render it certain whether these red rocks are equivalent to the Onondaga salt group or the Medina sandstone; but it is thought probable, from some of the mineral characters, no fossils having been seen, that they belonged to the epoch of the Medina sandstone, and that the subjacent Shawangunk grit is equivalent to the gray sandstone [Oswego] instead of the Oneida conglomerate."‡

* The writer is greatly indebted to J. Waldo Smith, Chief Engineer of the New York City Board of Water Supply, for permission to use the figures from the official records in this paper, and also to L. White, Division Engineer, under whose supervision he was working while collecting these data.

† Grabau, A. W., Jour. of Geol., vol. xvii, pp. 245–246, 1909; Bull. Geol. Soc. Amer., vol. xxiv, pp. 472–496, 1913; Principles of Stratigraphy, pp. 377, 596, 636, 1913.

‡ Geology of New York, First District, p. 355, 1843.

Darton, while describing the geology of Ulster county,* tentatively correlated these beds with the Clinton, Medina, and Oneida, but he states that: "The evidence as to the precise equivalency of these beds between the Shawangunk grit and Salina formation, in Ulster county, is unsatisfactory. No fossils have been found and the physical characters are not wholly distinctive. The quartzite and calcareous upper member is thought to represent the Clinton formation, for the upper part of this horizon is characterized by somewhat similar beds in western New York. The lower red beds may also be Clinton, but as they appear to expand into a series of red sandstones southward, it is suggested that they are of Medina age."

Careful stratigraphic work on the overlying limestone beds disclosed an error in the early correlations of these beds† and cast a doubt upon the supposed age of the subjacent sandstones, shales and conglomerate. When an Eurypterid fauna was discovered in the partings of the Shawangunk conglomerate this bed was definitely correlated with the Salina of western New York,‡ and the overlying beds must, therefore. be of Salina age or later. Some doubt seems to exist, however, concerning the relation of these shales and sandstones to the underlying Shawangunk and to the overlying limestones and cement beds. These contacts have frequently been described, but the descriptions do not agree with the observation of the writer, and a somewhat more detailed description of these contacts or transitions may throw a little light on the relations of the beds.

A great unconformity has always been recognized between the Shawangunk conglomerate and the underlying Hudson River shale in Ulster county, but no detailed description of this contact is known to the writer. The upper contact of the Shawangunk conglomerate with the overlying shale (now generally called the High Falls shale in this vicinity) has been described in detail by Hartnagel, but his description does not agree with the observations here given. He states that: "In the eastern section these shales are entirely devoid of pebbles, generally of a bright red color and uniform in character, specially near their base. On exposure to the atmosphere they break into small angular fragments which are easily washed away, leaving the sloping surface of the conglomerate beneath clean and white. . . . It is evident then that there is a very marked change in the character of the sedimentation following the conglomerate, suggestive of a hiatus at this point."§

* Report of the New York State Geologist, 1893, pp. 307–309.

† C. A. Hartnagel, Rept. N. Y. State Paleontologist, 1903, pp. 342–358.

‡ Science, Nov. 16, 1906; N. Y. State Mus. Bull. 107, pp. 295–310.

§ C. A. Hartnagel: Notes on the Siluric or Ontaric Section of Eastern New York, Rept. N. Y. State Paleontologist, 1903, p. 345 (1905).

More recently Grabau has assigned these beds to a continental or non-marine origin and placed a hiatus or disconformity between the upper member and the overlying cement beds and limestones.*

All of the authors referred to above have studied these beds either in natural outcrops or in exposures uncovered in the Rosendale-Whiteport Cement region. One feature, which throughout this whole region conceals the true relations of adjacent beds, seems to have been undervalued in these descriptions and that is the faulting of the region. Almost innumerable faults cut up and complicate the geology of this region. Both gravity and thrust faults are present, but the thrust faults predominate. These range all the way from a few feet up to several hundred feet in throw. Moreover, the effect of faulting is not confined to fault planes or fault fractures superinduced upon the rocks at the time of faulting, but movement has frequently taken place along the bedding planes. These fault movements seem to favor the bedding planes between the beds of different physical character and they often obscure the natural transition between successive beds. Perhaps faulting near the contact has given the impression that the change from Shawangunk conglomerate to High Falls shale is more abrupt than it really is. The same is true of the transition above to the Binnewater sandstone and from this to the overlying cement beds or limestones.

Description of sections.—The studies on which this paper is based were commenced in the summer of 1906, under the direction of the Department of Geology of Columbia University. They were continued through two full years from 1907 to 1909, while the writer was employed by the New York City Board of Water Supply as inspector of test borings during the preliminary survey and as a member of the engineering field force during the construction of the Rondout Siphon shafts and tunnels. A large number of core borings were drilled and five shafts were sunk in whole or in part through these beds. These offered exceptionally good opportunities for observing the relation of these beds in their natural unweathered and undisturbed condition and of making accurate measurements of the thickness at different points along a line some two and one-half miles in length.

The present paper will consider only the formations included between the unconformity at the top of the Hudson River shale and the base of the Upper Silurian limestones or cement beds. In this region these formations include three distinct members. At the base comes the Shawangunk conglomerate with a

* Jour. of Geol., vol. xvii, No. 3, p. 252, 1909.

maximum thickness in this vicinity of 284 feet where the full formation was probably present and not increased in thickness by dip of beds, folding, or faulting. Above this comes the High Falls shale, a series of red, green, and black shales, somewhat variable in thickness, in color, and in physical char-

Fig. 1.

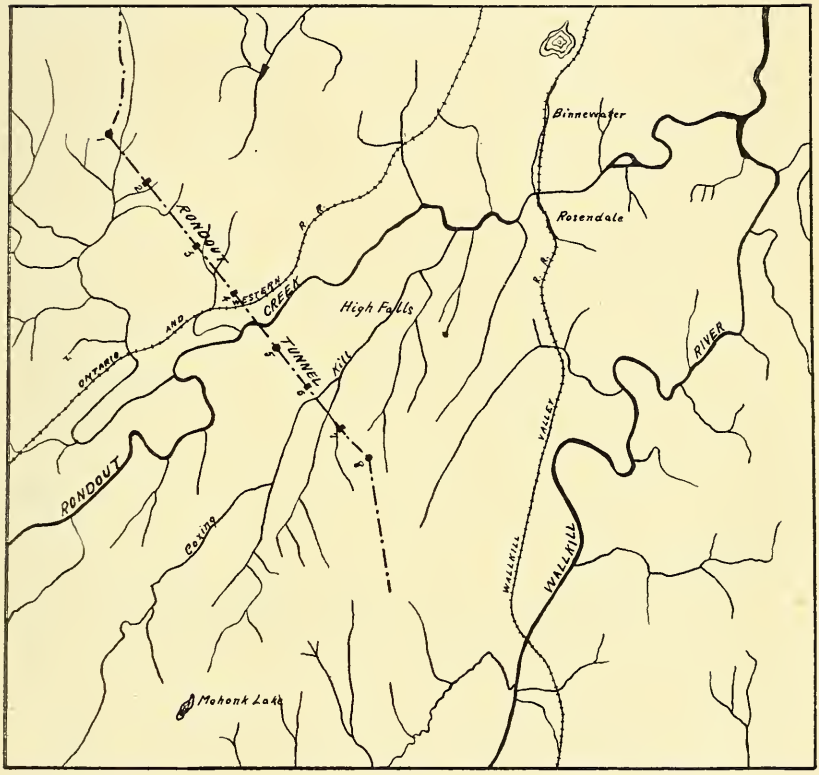

Fig. 1. Sketch map of the region near High Falls, N. Y., showing the location of sections here described. Scale : half-inch to the mile.

acter even in closely adjacent areas. The upper member is the Binnewater sandstone, a bed which in the type locality at Binnewater, some four miles northeast of High Falls, is a dense white quartzite, but which in this locality retains the quartzite character only for a few feet near its upper limit and is a thin-bedded, porous sandstone, interbedded with green shale throughout the greater part of its thickness.

The following measurements made from core borings at the points indicated on the accompanying cross section (fig. 2) will show how variable these beds are within narrow limits:

Hole No.	Overlying material			Binnewater sandstone	High Falls shale	Shawangunk conglomerate
6	514	drift & l. s.		(142′ not separated)		
32	240	"	"	55	67	133*
35	248	"	"	52	82	5*
10	238	"		62	99	5*
12	78	"		70	90	6*
14	67	"			44*	3*
23	21	"				284
20	38	"			3*	268
11	6	"			68*	345‡
36	54	"			20*	409†
38	31	"			59*	6*
19	100†	Hudson River				295
27	221†	"	"			78†

A (*) indicates that the boring did not penetrate the full thickness of the bed.

A (†) indicates that the position or thickness was due to faulting.

(‡) This value was greater than the normal thickness of the formation because of the angle of dip.

Fig. 2.

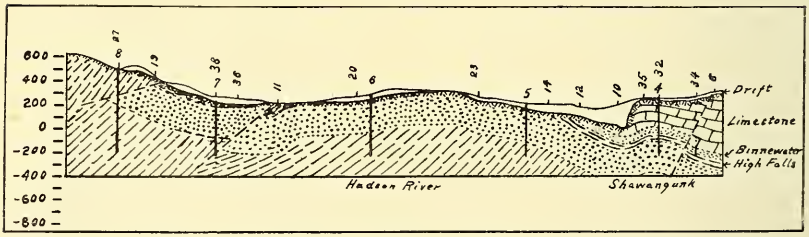

Fig. 2. Geologic section along a portion of the Rondout tunnel line. Vertical scale two and one-half times the horizontal.

From these measurements it is evident that the approximate thickness of the Binnewater sandstone is 55 to 60 feet. In hole 12, where the thickness is given as 70 feet, the underlying shale is thinner than in the adjacent hole 10, so that an error may have been made in drawing the line between these two members when examining the core. If this be true, then the thickness of this formation varies from 52 to 62 feet for this vicinity. This measurement agrees very closely with a measurement made in the gorge of the Rondout below the falls.

The High Falls shale is more variable in thickness as well as in color and physical character in the various drill holes. The larger values given above, that is 90 to 100 feet, more nearly agree with the thickness exposed in the gorge.

The Shawangunk conglomerate probably does not exceed 280 feet in thickness within this limited area. Where the measured thickness is greater than this it has been affected by folding or faulting, as is shown on the accompanying diagram (fig. 2).

These measurements, made in core borings and checked by accurate measurements in the shafts during construction, and by a comparison with the beds exposed in the gorge below the falls, differ materially from those given by Mather and by Darton. Their measurements are introduced here for comparison:

Average section		Mather's section			Darton's section	
		No.				
Cement beds	--	3	Cement rock	6–8	Cement	--
Binnewater sandstone	55	4	Pyritous slaty limestone	4–10	Clinton to Medina	40
High Falls shale	90	5	Red shale	15–20		
Shawangunk conglomerate	270	6	Conglomerate		Shawangunk	--

In a cut on the Wallkill Valley railroad near Binnewater the full section between the cement beds and the Hudson River shale is exposed. This section gave the following measurements:

Binnewater sandstone	32 feet
High Falls shale Shawangunk conglomerate	78 "

The contact between the Shawangunk conglomerate and the High Falls shale is concealed in this section, so that the individual measurements of these beds could not be obtained. In a drainage tunnel of the consolidated Rosendale Cement Company, a few hundred yards away, a similar section was exposed. Although this was not accessible for accurate measurement, the thickness of the conglomerate was estimated at ten feet, and this value was probably the approximate thickness in the section given above.

In this Binnewater section the Binnewater sandstone is a dense white or pale gray sandstone approaching a quartzite throughout. The High Falls shale is a soft, fine-grained, bright red shale with very little material of any other color. The Shawangunk conglomerate consists of quartz pebbles in a somewhat darker colored matrix. In this exposure the details

of the contacts or transitions from bed to bed could not be observed.

In the gorge of Rondout Creek below the falls the Binnewater sandstone is approximately 50 feet thick. The upper three or four feet is a white quartzitic sandstone similar to the whole formation at Binnewater. Beneath this it consists of alternating beds of shale and sandstone, gray to greenish in color and very soft and friable. Many of the bedding planes show ripple marks and sun cracks. The boundary between this and the underlying shales is not distinct. The one formation passes gradually into the other, the sandy layers becoming less prominent, and being replaced by proportionately more and more shale.

The High Falls shale consists of three practically distinct members, an upper shale extending from the base of the Binnewater sandstone to the little fall at the old grist mill, a middle sandstone twelve feet thick giving rise to this fall, and a lower shale extending down to the Shawangunk conglomerate. The upper shale is mostly dark gray to black in color, but it has a number of green shale beds and one dark reddish colored bed several feet thick near its base. The middle sandstone is almost black in color. The lower shale consists of alternating green and red shales, the red color predominating. But even in this member the red is not as brilliant as in the Binnewater section.

These three members can be distinctly recognized in the cores from some of the drill holes. Their thickness in three of the holes was as follows:

Hole No.	Upper shale	Middle sandstone	Lower shale
12	27	15	48
10	37	13	50
32	27	12	40

Hole No. 6 did not penetrate the full thickness of the High Falls shale. Moreover, the shale varied so much in both color and texture in this hole that the division into members and correlation with the other holes could not be carried out. Only a few feet near the lower part of the core showed any red color, while the greater part of the formation (60 feet) consisted of a dark, almost black sandstone. Hole 32 also showed only a few feet of shale with a dark reddish color, the rest being dark green, dark gray, or black.

Shafts 5, 6, 7, and 8 of the Rondout tunnel each penetrated one or more of the beds under discussion. As these beds were in every case opened up at a considerable distance beneath the surface, where weathering had not reached the materials and where circulating waters had not produced any important effects, an exceptional opportunity was afforded to observe

these beds in an unaltered condition. Furthermore, the fresh cut made it possible in every case to observe the contacts or transitions between formations.

In shaft 8, only the lower thirty feet of the Shawangunk conglomerate was penetrated; all the higher beds were cut out by an overthrust fault which brought the Hudson River shale to rest upon this lower part of the conglomerate (see fig. 2). The lower contact of the conglomerate with the Hudson River shale was distinctly shown, and it was a distinct erosional unconformity. The irregular contact rose nearly four feet over a rounded projecting mass of shale at the center of the shaft. At the base of the conglomerate was a thin layer of bright green or olive-green shale. The first few feet of the conglomerate consisted of large quartz pebbles up to two inches in diameter in a dark matrix. Above this it became pure white in color and was largely sandy in texture.

Shaft 7 penetrated 35 feet of drift, mostly finely laminated clay, 54 feet of High Falls shale, and 174 feet of Shawangunk conglomerate, and then entered the Hudson River shale. At this point the High Falls shale consisted of alternating bands of red and green, the red predominating. The bands of color did not always correspond with the bedding planes; the red color seemed to be due rather to the action of oxidizing waters. Many of the larger masses of rock brought out during the excavation of the shaft were mottled with red and green in an irregular manner.

The transition from the conglomerate to the shale was clearly shown in this shaft and it was a rather gradual one. The upper six or eight feet of the conglomerate consisted of quartz pebbles in a dark shaly matrix. Above this came two feet of mingled red and green shales containing numerous quartz pebbles. The quartz pebbles decreased in number from the bottom to the top of this two-foot layer, completely failing in the overlying shale. One rather remarkable feature about these pebbles was that they were larger than the average size of the pebbles in the conglomerate below. The transition, however, was a gradual one and there could be no gap in the record as suggested by Hartnagel.

The lower contact of the Shawangunk conglomerate with the Hudson River shale was also well shown; it was in a fresh and undisturbed condition. A thin layer of bright olive-green shale occurs at the base of the conglomerate and unconformable with the underlying shale.

Shaft 6 passed through 26 feet of drift consisting of bowlder clay or till with numerous large bowlders and many pebbles. Then it penetrated the Shawangunk conglomerate with a thickness of 277 feet. The upper surface had suffered glacial erosion and possibly a few feet of conglomerate may

have been removed. The upper bed consisted of coarse quartz pebbles embedded in a finer grained matrix. Ten feet from the upper surface came a layer of olive-green shale one foot thick and beneath this the rock was mostly fine-grained, pure white sandstone with occasional conglomerate beds. There were several layers of the green shale a few inches in thickness and occasional partings of black shaly material a fraction of an inch thick. The contact of the conglomerate and the Hudson River shale was also well shown in this shaft. The unconformity was sharply defined; the Hudson River beds were dipping at a considerable angle and the lower part of the Shawangunk beds consisted of two to three feet of light olive-green shale. Above this the conglomerate was hard and coarse-grained.

Shaft 5 passed through 50 feet of drift, partly till and partly laminated clay, and then penetrated the Shawangunk conglomerate, 255 feet thick, under conditions similar to those described for shaft 6.

Shaft 4 passed from the overlying limestone through both the Binnewater sandstone and High Falls shale into the Shawangunk conglomerate. The thickness of these beds has been given above under Hole 32, which occupied the same position. This shaft exposed the best unweathered section of the Binnewater sandstone; it consisted at the top of a dense quartz sandstone layer and below of alternating sandy and shaly bands a few inches thick; it was gray to greenish in color and contained considerable calcareous material. Quite a proportion of this calcareous material had been dissolved out, leaving the rock porous and honeycombed, with numerous cavities often lined with minute calcite crystals. The High Falls shale in this shaft was green to black in color, rather porous in places and it contained a considerable amount of iron pyrite. Iron pyrite also occurred in the upper few feet of the Shawangunk conglomerate.

Summary of Observations.—The observations on these three formations in the vicinity of High Falls may be summarized as follows:

Binnewater sandstone.—In the type locality near Binnewater this sandstone is dense, white, and quartzitic, 32 feet thick. In the gorge of the Rondout at High Falls only a few feet at the top have the characteristics of the formation at the type locality. The remainder of the formation consists of thin-bedded alternating shaly and sandy layers, often showing ripple marks and sun cracks, and gray to green in color. In shaft 4, the locality farthest from the outcrop of any section studied, the upper thin layer of white quartzitic sandstone was recognized. Below this the formation consisted of alternating thin beds of sand and shale, often calcareous and with

numerous cavities frequently lined with minute calcite crystals. The transition from the underlying shale and to the overlying limestone is gradual, not an abrupt contact.

High Falls shale.—In the Binnewater outcrop the High Falls shale is almost wholly a fine-grained, bright red shale with subordinate green layers, approximately 68 feet thick. In the gorge of the Rondout it consists of three easily separated members, an upper shale, a middle sand, and a lower shale. The upper shale member is predominantly green or gray in color with a subordinate bed of dark red. The middle sand is dark, almost black in color, and the lower shale is predominantly red, although much darker and less conspicuous than the Binnewater outcrop. These three members can be recognized in shaft 4, and in some of the core borings along the Rondout tunnel line, but at a distance from the outcrop the red color almost fails and is replaced by green or black. The exposure of these beds in shaft 7 shows that the bands of color do not always correspond to the bedding planes, and the red color is evidently due to oxidation by surface waters. Many of the beds are irregularly mottled green and red. The transition from the underlying conglomerate and to the overlying sandstone is in each case where well exposed a gradual change, not an abrupt contact or unconformity. In the unweathered exposure of shaft 4, iron pyrite is present in considerable amounts.

Shawangunk conglomerate.—In the Binnewater outcrop this is a thin conglomerate layer about ten feet thick. The various shafts and borings along the tunnel line show that where it is neither reduced nor increased in thickness by faulting or folding this formation varies from 174 to 284 feet. The lower limit of the formation is a distinct unconformity. At the base of the conglomerate there is always a layer of bright olive-green shale varying in thickness from a few inches to several feet. Similar green shale layers occur at several points within the formation and vary from a few inches to a foot thick. Occasional black partings a small fraction of an inch thick occur. The conglomerate is slightly coarser grained at the base and at the top, and at a few intermediate points, but throughout the greater part of its thickness this formation is a pure white quartz sandstone rather than a conglomerate. Cross bedding on a small scale is common. The transition to the shale above is rather gradual. Occasionally iron pyrite occurs near the upper limit of the formation.

A careful search during the excavation in these three formations failed to discover any trace of fossils.

Conclusion.—These three formations evidently make up a continuous and unbroken series, extending from the unconformity at the base of the Shawangunk conglomerate up to.

and grading into, the Rosendale cement bed of the Upper Silurian.

The red color of the High Falls shale, which has been considered an evidence of the deposition of these beds under desert or at least subaërial conditions, is not an original character, but has been produced by comparatively recent weathering and practically fails where these beds are uncovered away from the outcrop or the effects of circulating ground waters.

The pure white color of the Shawangunk conglomerate with included layers of bright green shale cannot be readily explained on the theory of subaërial deposition, under the arid climatic conditions postulated for Salina time, and the fine-grained sandy character of this formation throughout the greater part of its depth is hardly consistent with the torrential theory of its origin.

The presence of considerable quantities of iron pyrite in the High Falls shale and upper part of the conglomerate is not consistent with the subaërial, alluvial fan theory of origin in an arid Salina climate. The green color of the shale layers in the conglomerate and their great preponderance in the unweathered sections of the High Falls shale as well as the presence of iron pyrite in the latter formation indicate that the beds were deposited under conditions such that the iron was subjected to reduction, not oxidation. This would imply either subaqueous deposition or the presence of abundant vegetable or other organic matter. We have no evidence that land vegetation was abundant during the Salina epoch and the total lack of fossils would further indicate that the reduction was not brought about by organic matter. It seems necessary, therefore, to conclude that these formations were deposited under water.

The thin-bedded Binnewater sandstone containing considerable amounts of calcium carbonate and grading upward into the hydraulic cement bed and then into the normal marine Cobleskill limestone cannot be explained, in so far as the writer can see, as other than a normal marine shaly sandstone. In this region, at least, there is no trace of a great break or hiatus during, or at the close of, this formation.

These facts lead to the unavoidable conclusion that in this region these three formations constitute a normal sequence at the base of a normal marine transgression during Salina and Upper Silurian time. They are overlapped to the north and east by higher beds, as we should expect in such a normal transgression. These beds cannot be interpreted as subaërial deposits of the alluvial fan type, and there is no apparent reason why they should be considered delta rather than normal shore deposits.

Bryn Mawr, Penn.

SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *The Peculiarity of Nickel and Cobalt Sulphides.*—The contradictory behavior of these sulphides in the fact that they are not formed in solutions of strong acids and that when once formed they are practically insoluble in strong acid solutions is well known to every student of analytical chemistry, as it is contrary to an almost universal rule governing precipitation. A. Thiel and H. Gessner have made an elaborate study of this matter by precipitating nickel sulphide under various conditions, treating the precipitates with acids for varying lengths of time, repeating the treatment with the undissolved residues and determining quantitatively the amounts of nickel dissolved. They believe that they have explained the contradictory behavior of nickel sulphide in its essential features, for they find that an easily soluble nickel sulphide exists, but that it undergoes a spontaneous modification into more difficultly soluble sulphide, probably on account of polymerization. It is their opinion that besides the soluble sulphide, which they designate as the α-modification, two other modifications, β and γ, exist. They consider it highly improbable that the soluble form, the α-NiS, is a hydrate as has been surmised. They find that all the modifications have the same empirical composition, corresponding to NiS, and on this account they believe that polymerization takes place. —*Zeitschr. anorgan. Chem.*, lxxxvi, 1. H. L. W.

2. *The Dimethyl Phosphates of the Rare Earths.*—In connection with the important rare earth investigations that are being carried on at New Hampshire College by Professor James, J. C. Morgan and C. James have prepared the dimethyl phosphates of a number of rare earths and have studied their solubilities with the following results :

Element	Parts of salt per 100 Parts of water at 25°
Lanthanum	103·7
Cerium	79·6
Praseodymium	64·1
Neodymium	56·1
Samarium	35·2
Gadolinium	23·0
Yttrium	2·8
Erbium	1·78
Ytterbium	1·2

They have applied these salts to the fractional separation of several mixtures of the earths, and find that the rate of separation is vastly greater than practically all the methods given up to the present time. Lanthanum, cerium, praseodymium and neodymium

are left at once in the mother liquor. Samarium, europium and gadolinium are much less soluble than those just mentioned, but they are more soluble than terbium, dysprosium and holmium. Erbium, thulium, yttrium, ytterbium, etc., collect in the least soluble portions. Since the solubilities of these compounds are the reverse of the usual type, they can be used for the rapid purification of many of the rare earths. For instance, traces of neodymium can be easily removed from samarium by this means, as the samarium compound separates before the other one. There is some inconvenience in working with these salts, since they undergo gradual decomposition, with the formation of a gelatinous precipitate which filters with difficulty.—*Chem. News*, cix, 13. H. L. W.

3. *Qualitative Chemical Analysis*, by ANTON VORISEK. 8vo, pp. 226. Philadelphia, 1914 (P. Blakiston's Son & Co. Price $2.00 net.).—This is a text-book for laboratory use, dealing with the common elements and their compounds. The course of analysis presented is an unusually extensive and satisfactory one. The directions are full and clear and the explanations are excellent. It rarely happens that a new text-book on qualitative analysis makes so good an impression upon examination as this one. In connection with the descriptions of the reactions the equations are put in a compact form by putting the substance reacted upon at the top, the reagent below it, and the products of the reaction under a line. For example :

$$\begin{array}{r} ZnCl_2 \\ +(NH_4)_2S \\ \hline = ZnS + 2NH_4Cl \end{array}$$

The author has made a few modifications in the usual course of analysis, such as the precipitation of manganese in the ammonium hydroxide group by the addition of hydrogen peroxide, the separation of the sulphide, ferrocyanide and ferricyanide radicals from the rest of the silver nitrate group by means of cadmium nitrate, and so on. H. L. W.

4. *Introduction to Modern Inorganic Chemistry*, by J. W. MELLOR. 12mo, pp. 684. London and New York, 1914 (Longmans, Green and Co. Price $1.30).—This text-book is a simplification of a considerably larger one by the same author which appeared about two years ago and was very favorably noticed on account of breadth of scope and interesting style. However, it did not appear to be a suitable book for the use of beginners on account of its size and character. The present book presents the subject somewhat more conventionally and briefly than the other. It is very able and interesting, retaining to a large degree the admirable features of the previous work. It is to be highly recommended to readers in search of fundamental chemical information, but perhaps even the condensed form may be considered somewhat too elaborate for use as a drill-book with the majority of beginners. H. L. W.

5. *The Practical Methods of Organic Chemistry*, by Ludwig Gattermann. Translated by Schober and Babasinian. 12mo, pp. 401. New York, 1914 (The Macmillan Company).—This is the third American edition, corresponding to the eleventh German edition, of a book that is so well known and so widely used in connection with the preparation of organic compounds, that it is only necessary to say that the new edition contains some important but not very extensive additions. H. L. W.

6. *Spectrography of Röntgen Rays.*—A spectrograph for X-rays, giving lines which compare favorably in sharpness with ordinary spark spectra, has been devised by Maurice de Broglie and used very successfully by the inventor and by several other investigators. A beam of X-rays is caused to pass through a rectangular slit in a lead block and to fall upon the plane face of a suitable crystal. This crystal is slowly rotated by clockwork (or otherwise) around an axis which is parallel to the slit, which lies in the reflecting surface of the crystal, and which intersects the axis of the X-ray beam at the point of incidence. The crystal behaves like a three-dimensional grating and brings the radiations to foci whose centers lie on the arc of a circle passing through the point of incidence on the crystal surface and having a radius equal to the distance between the point of incidence and the point where the beam of X-rays forms an effective slit. If a photographic film is bent into the form of a cylinder containing the arc just defined, the X-ray spectra will be recorded as the crystal is slowly rotated. The glancing angle α and the wave-length λ will satisfy the well-known relation $n\lambda = 2d \sin \alpha$. It is easy to show mathematically that, for small wave-lengths, the spectra will be *normal*. By rotating the dispersing crystal in both directions with respect to the incident beam, spectra of positive and negative orders will be registered and hence any uncertainty as regards the exact point of incidence can be avoided. In general, sufficiently accurate results can be obtained by using a plane photographic plate, placed as a mean chord of the focal circle, instead of a cylindrical film. Furthermore, the apparatus can be used as a direct vision spectroscope by substituting a suitable phosphorescent screen for the photographic plate.

The negatives obtained by de Broglie are very clear, and beautiful from the scientific standpoint. The general appearance of the spectra may be briefly described as follows: They commence at the short wave-length side with two bands which appear to be continuous. The narrower band is very intense and has a sharply defined boundary at the longer wave-length side. The wider band is much weaker and shades off gradually towards the longer wave-lengths. Near the outer edge this band is associated with fine lines. The angle corresponding to the head of the weaker band is about twice as large as the angle for the head of the stronger band. The indefiniteness of the outer limit of the weaker band makes it impossible to tell whether the factor is exactly two, that is, whether the diffuse band is simply the second

order spectrum of the more intense image. These bands are produced by very penetrating radiations which play the most important part in X-ray phenomena when the total emission is not minutely analyzed. They probably represent the electromagnetic radiation caused by the sudden stopping of the cathode rays by the anticathode. The rest of the spectrum consists of sharp, discrete lines superposed on a much fainter, continuous background. By using an absorbing screen of glass 1^{mm} thick it was found that the "lines" practically disappeared while the background was only weakened. This shows that the continuous spectrum belongs to higher orders of the central bands. The "lines" are similar to ordinary spectral lines, being single, multiple, sharp, diffuse, strong, weak, etc. For details of wavelengths, dispersive power of various crystals, and many other important data reference must be made to the original article.—*Jour. de Phys.*, vol. iv, Feb., 1914, p. 101. H. S. U.

7. *Removal of the Photoelectric Effect of Potassium.*—In the March number of this Journal attention was called to the experimental work of Küstner in which the photoelectric effect of zinc was entirely suppressed. This very important result confirms the hypotheses advanced several years ago by W. Hallwachs as well as the theoretical considerations and experimental facts recently published by this investigator in collaboration with G. Wiedmann. (The earlier work happened to appear in print after the later. The priority seems to belong to Hallwachs and Wiedmann rather than to Fredenhagen and Küstner.)

Starting with the idea that the photoelectric effect exhibited by metals could be suppressed by removing the last traces of gases, Hallwachs and Wiedmann investigated potassium and hydrogen, since the alkali metals give the strongest effect, since potassium is always used in photoelectric cells, since hydrogen is usually present in such cells, and since potassium absorbs hydrogen in remarkably large quantities. (One volume of potassium absorbs 126 volumes of hydrogen.) In other words, if it could be shown that potassium, which initially contained a great deal of hydrogen, could have its photoelectric properties destroyed by freeing it completely from this gas, the result would afford the strongest evidence in favor of the hypothesis that the presence of a gas is a necessary condition for the existence of the photoelectric effect in metals. The apparatus used was of too complicated a design to admit of easy description without the aid of a diagram. Suffice it to say that five glass bulbs were so arranged as lateral branches of a long evacuating tube as to enable the experimenter (Wiedmann) to distil with extreme slowness the potassium from one bulb to the next in the series. Each bulb could be sealed off at will and tested for its photoelectric effect by comparison with a standard cell. The fourth bulb, which contained thrice distilled potassium, gave about the same deflection before and after illumination. This was largely due to surface conduction. After several days it was possible to suppress

this conduction and then the fourth cell, when illuminated, gave a deflection of 14^{mms} as contrasted with 850^{mms} for the standard cell. The fifth cell, containing potassium which had been distilled four times, did not give the slightest photoelectric effect even when the slit between the lamp and the cell was opened so wide that the standard cell could no longer be used for comparison. The entire experiment was repeated with similar results. Consequently, it has now been shown that the photoelectric effects of potassium and zinc can be completely suppressed by removing all traces of gases.— *Verh. d. deutsch. physik. Gesellsch.*, No. 2, p. 107, 1914. H. S. U.

8. *Heat of Formation of Hydrogen from Hydrogen Atoms.*— In an important theoretical paper on the constitution of atoms and molecules N. Bohr has calculated the heat of formation of hydrogen molecules from the atoms to be 60,000 calories per gram-molecule. On the other hand, the experimental work of Irving Langmuir gave the much higher value 130,000. This discrepancy incited the latter investigator to repeat his work with greater care and under more favorable conditions. The method adopted was similar to that previously used and it consisted in the determination of the heat-loss from tungsten wires heated electrically in hydrogen. The gas pressures ranged from 1^{mm} to 760^{mms} of mercury. By subtracting the heat-loss due to normal heat-conduction from the total observed heat-loss, the heat carried by diffusion of the hydrogen atoms was deduced. When the logarithm of this quantity was plotted against the reciprocal of the absolute temperature, straight lines were obtained for each experiment, and the slopes of all these lines were practically equal and independent of the pressure of the hydrogen gas. Assuming that the diffusion coefficient varies with the $\frac{3}{2}$ power of the temperature, it follows that the heat of formation of hydrogen is about 76,000 calories per gram-molecule instead of 130,000 as previously determined. The higher value was based on a calculation of the actual value of the diffusion coefficient of hydrogen atoms through ordinary hydrogen. The more recent results show that the degree of dissociation is much smaller than had been found in the earlier work, and that at temperatures as high as 3500° K. hydrogen is probably not dissociated to a very great extent. Langmuir concludes that the experimental evidence now indicates a value between 75,000 and 80,000 calories and that it seems very improbable that the heat of formation of hydrogen molecules can be as low as 60,000, which is the figure derived from the theory of Bohr.—*Phil. Mag.*, xxvii, p. 188, Jan., 1914. H. S. U.

9. *Thermal Expansion of Quartz Glass.*—The absolute expansion of quartz glass, between +100° C. and −253° C., has been investigated by Karl Scheel and Wilhelm Heuse. The specimen was made in the form of a ring of $9{\cdot}942^{mms}$ altitude, and the method followed was the well-known interference scheme due to Fizeau. The expansions of the ring in the intervals −253° C. to +16° C., −190° to +16°, −78° to +16°, and +16° to +100°

were $-0{\cdot}71^{\mu}$, $-0{\cdot}15^{\mu}$, $+0{\cdot}24^{\mu}$, and $+0{\cdot}44^{\mu}$ respectively, The curve representing these data passes through a minimum at about $-80°$ C. and is perfectly "smooth" at higher and lower temperatures. The equation of the curve is given as "$l_t = l_0[1 + 0{\cdot}362 \times 10^{-6}.t + 0{\cdot}001813 \times 10^{-6}.t^2 - 0{\cdot}00000340 \times 10^{-6}.t^3]$." The investigators point out the danger associated with the assumption, often made, that the expansion of fused silica is negligible. In particular, this assumption caused certain data given by Lindemann to deviate from the correct values by as much as 30 per cent. Since the work on quartz glass was carried out at the Bureau of Standards at Charlottenburg it is doubtless very trustworthy.— *Verh. d. deutsch. physik. Gesellsch.*, No. 1, p. 1, 1914.

H. S. U.

10. *Physics for Technical Students. Mechanics and Heat;* by William Ballantyne Anderson. Pp. xi, 349; 153 figures. New York, 1914 (McGraw-Hill Book Co.).—This book emphasizes the practical applications of the subjects discussed because it is designed primarily to meet the needs of classes in Agriculture and Engineering. With this end in view special care has been given to the text figures, which are, without exception, well-drawn and clearly printed. The author says: "Wherever possible, every principle involved in the text is brought up again in a problem; so that in working all of the problems a review of practically the entire book is obtained." "For a complete course, the text should be accompanied by lectures and laboratory work."

The subject-matter is divided into three Parts treating respectively of Mechanics (133 pages, 124 problems), Properties of Matter (78 pages, 43 problems), and Heat (116 pages, 36 problems). (Answers to the problems are not given.)

The author's style is clear, logical and attractive. The topics discussed are presented in a thoroughly scientific manner so that the usefulness of the volume should not be restricted to purely technical classes. "More space than usual has been devoted to the treatment of Force, Torque, Translatory Motion, and Rotary Motion." On the other hand, the text is enhanced by not being encyclopedic. Unusual care has been taken to minimize errors of all kinds and the book makes such a pleasing impression that it merits a successful future. H. S. U.

11. *Natural Sources of Energy;* by A. H. Gibson. Pp. viii, 131; 17 figures. Cambridge, 1913 (University Press).— This little book is devoted to a discussion of the world's energy problem and the possibilities of its solution. A short chapter on the transformation of energy is followed by three chapters on the utilization of fossil fuels, of solar heat, and of vegetation for power purposes respectively. Attention is then turned to a consideration of the internal heat of the earth and of various natural sources of power, such as water, tidal, and wind power. It is thus seen that the author wisely avoids entering the highly speculative field afforded to the fertile imagination by the recent discoveries in the domain of molecular physics. The maps showing the distribution over the surface of the earth of regions of intense

solar heat accompanied by small annual rainfall, of luxuriant vegetation, and of large water power are specially instructive. The volume ends with "References," "Bibliography," and a subject index. H. S. U.

12. *Effect on the Propagation of Electric Waves of the Total Eclipse of the Sun, 21st August, 1914.*—A committee of the British Association for the Advancement of Science has recently issued the following circular:

"The forthcoming total eclipse of the sun affords an exceptional and important opportunity of adding to existing knowledge of the propagation of electric waves through air in sunlight and in darkness, and across the boundaries of illuminated and unilluminated regions. The eclipse will be total along a strip extending from Greenland across Norway, Sweden, Russia and Persia to the mouths of the Indus. In Russia the duration of totality will be a little more than two minutes.

"There are two main points calling for investigation during the eclipse. In the first place, the propagation of signal-bearing waves through air in the umbra and penumbra will probably obey laws different as regards absorption and refraction from those obeyed in illuminated air. In the second place, the strength, frequency and character of natural electric waves, and of atmospheric discharges, may vary. The variations may occur either because the propagation of natural waves from distant sources is facilitated or impeded by the eclipse, or, possibly, because the production of natural electric waves or atmospheric discharges is for some unknown reason affected by the eclipse. These points have previously been investigated to only a slight extent. The observers of signals during the solar eclipse of 17th April, 1912, nearly all agreed that the strength of the signals was greater during the eclipse than an hour before or after. There was only one special observation of strays during the same eclipse, when very pronounced and remarkable variations were recorded during the passage of the shadow-cone across Europe.

"To investigate the propagation of signals across the umbra it will be necessary to arrange for wireless telegraph stations on either side of the central line of the eclipse to transmit signals at intervals while the umbra passes between them. This transit of the umbra occupies about two minutes. It is thus very desirable that the Scandinavian and Russian stations should transmit frequently throughout several times before, during, and after totality. But stations other than those favoured by their proximity to the central line should endeavor to keep a complete record of the variations of signals during the eclipse. Stations in Europe west of the central line and stations in the Mediterranean and in Asia Minor may find noticeable changes in the strength of signals, particularly long distance signals, between the hours of 10 A. M. and 3 P. M., Greenwich time; and it is probable that the stations of India and East Africa, and ships in the Indian Ocean, may feel the effect of the penumbra in the afternoon. On the other hand, ships in the Atlantic, and fixed

stations in Eastern Canada and the United States, will probably be affected by the penumbra in the early morning. At Montreal the eclipse (partial) is at its greatest phase at 5.52 A. M. Standard time. It is possible that the eclipse may have some influence even when it is invisible.

"The investigation of strays is of as great interest as that of signals. So far as is yet known, the natural electric waves reaching wireless telegraph stations in latitudes higher than 50° appear to travel mostly from the south. Thus the greatest changes produced in strays by the eclipse will probably be experienced at stations in Scandinavia and Russia, to reach which the waves must cross the path of the umbra. At the same time changes of some kind are to be expected in other districts than these, and it is therefore desirable that statistical observations of natural electric waves be made all over the world, and especially at places within an earth quadrant of Southern Russia. It is also desirable that meteorological observations, including those of atmospheric ionization and potential gradient, should be at the disposal of the committee when considering the records of strays and signals.

"The committee propose to prepare and circulate special forms for the collection of statistics of signals and strays, especially within the hemisphere likely to be affected by the eclipse ; they will endeavour to make provision for the transmission of special signals at times to be indicated on the forms ; and they will offer for the consideration of the authorities controlling stations near the central line a simple programme of work. The discussion of the observations, and the comparison with meteorological data, will be carried out by the committee ; and digests of the statistics, together with the conclusions drawn from the analysis, will be published in due course.

"The committee would be greatly aided in the organization of this investigation if those possessing the necessary facilities and willing to make observations during the eclipse would communicate with the Hon. Secretary, Dr. W. Eccles, University College, London, W. C., at the earliest possible date."

II. Geology and Natural History.

1. *Manual of Petrographic Methods*, by A. Johannsen. Pp. xxviii, 649, 8°, figs. 764. New York, 1914 (McGraw Hill Book Co.).—This work, as its name implies, is not a text-book for beginners in petrology, but a volume of reference for workers of all classes in the subject. It is in some ways the most complete work of its kind that has yet appeared, containing more methods and material than even the first volume of the last edition of Rosenbusch's Physiographie. Every part of the petrographer's laboratory equipment, excepting of course that required in analytical chemical operations, is fully described, not only from the practical but also from the theoretical standpoint. The treatment of crystals both on the crystallographic and optical

sides is unusually full. Thus we find chapters on the stereographic projection, on general optical principles, especially wave motion, on the properties of isotropic media, two on anisotropic media, one on lenses, four on microscopes, one on the use and care of the microscope, three on methods with ordinary light, especially on methods of determining refractive indices, one on microscopical measurements ; then follow a series of chapters on observations in polarized light, with discussions of the phenomena produced in crystals, and of the implements to be used in studying and determining them. Determinations of specific gravity, mechanical separation of rock constituents, microchemical reactions, and the preparation of thin sections are each fully treated in separate chapters. This will serve to give a general idea of the ground covered in the volume. There is scarcely a phase of petrographic work, aside from chemical analysis, in which all methods that have been proposed are not here collected and discussed. Especially valuable is the very full bibliography which will enable one to consult the original sources from which the material has been gathered. The book is well written and the numerous figures helpful ; it is well printed and bound, and while the public to which it appeals is necessarily small, it will without doubt be greatly valued and used by its members. We commend it as a *vade mecum* to every working petrologist.

L. V. P.

2. *A History of Land Mammals in the Western Hemisphere;* by William Berryman Scott. Pp. xiv, 693, with frontispiece and 304 text figures. New York, 1913 (The Macmillan Company).—Professor Scott has produced an authoritative account of the fossil mammals of the western world, presented in such a manner as to be fully intelligible to the layman and a source of valuable information to the serious student. There are several introductory chapters on geological and paleontological methods, mammalian classification, and on the structure of the skeleton and teeth, a knowledge of which is so essential to the paleontologist. The succeeding chapters deal with the life histories of the more important mammalian orders, but the zoological sequence is reversed, which makes the book slightly confusing to the systematist. The last chapter is philosophical in tone, and emphasizes the exceptional difficulty of mammalian evolutionary problems, which experimental zoology and paleontology by combining their resources may eventually solve.

The book is admirably illustrated by clear anatomical drawings and numerous restorations by Bruce Horsfall and Charles R. Knight, all prepared under the careful supervision of the author.

R. S. L.

3. *Nomenclature of certain Starfishes ;* by A. E. Verrill. (Communicated.)—*Asterina.* In my Revision of this family* (this Journal, vol. xxxv, pp. 477–485, 1913), the specific name *minuta* was used for a dubious West Indian species. This name

* In that article an error occurs in the analytical table of genera, p. 479. Above line 4, from bottom, insert : DD. Interactinal plates without a fan of spines.

has been variously misapplied by authors to species from Europe, West Indies, and East Indies. It was apparently first used under the binomial system by Linné in Fauna Suecica, p. 512, 1761. In that place no locality was given, except "Mari Norvegico." Its size was given as that of a parsnip seed and it was said to be similar to *Asterias rubens*, and perhaps the young of that species.

There is nothing in the few words of description to show that it is not the young of *Asterias rubens*, or some similar species, and nothing to prove that it is the young of *Asterina gibbosa*, the only European species of *Asterina*. Certainly the name should not be used for any exotic species, although Linné himself later, in Syst. Nat., ed. xii, gave the West Indies as a locality. It should be dropped as indeterminable.

ANSEROPODA LUNA (Linné) = *Palmipes rosaceus* of authors.

Asterias luna Linn., Syst. Nat., ed. x, p. 661, 1758.

Asterias rosacea Lam., 1815; *Palmipes* or *Anseropoda rosaceus* of most recent writers.

The brief description given by Linné applies, without any reasonable doubt, to this well known East Indian species. Linné gives India as its locality. He puts it in a section destitute of rays; describes it as suborbicular, large, compressed, lunate, and with raised points above and below.

Acanthaster planci (Linné), Syst. Nat., ed. x, Appendix, p. 823, 1758 (as *Asterias*).

Linné here quotes a good figure of the Indo-Pacific species, from Goa, Asia, in Columna, Phytobasamus, pl. 36, fig. A. The specimen figured had fifteen rays. It is the species usually called *A. echinus* (Ellis) or *A. echinites* (Lam.). The name given by Linné must be adopted. It seems to have been generally overlooked. A. E. VERRILL.

4. *The Birds of Connecticut, Bulletin No. 20. Connecticut State Geological and Natural History Survey;* by JOHN H. SAGE, LOUIS B. BISHOP, and WALTER P. BLISS. Pp. 370. Hartford, 1913.—The greater part of this Report consists of a catalogue of all the birds, together with abundant records of the dates of arrival and departure, nesting habits, and particulars of the place and dates of occurrence of the rarer species. The second part (pp. 261–360) is devoted to Economic Ornithology, especially with reference to the food of the birds, and their utility as destroyers of insects and weeds. This part should appeal to all interested in the protection of our birds. The first parts show a great amount of care and time required for the accumulation of such data, during many years.

Naturally some omissions have occurred, and some additional records might have been added that would have been of use. Thus we notice that the Wood Ibis is omitted. Although rare, there is a Connecticut specimen in the Yale Museum. One interesting late occurrence of the Passenger Pigeon may be added. It was shot by A. H. Verrill on Davis Island, off Stony Creek, in the summer of 1889, while I was living on that island.

Others were seen the same season, on the adjacent mainland, in flocks of flickers. This is the last specimen known to have been shot near New Haven. It was preserved. On pp. 71 and 73 it is stated that the Carolina or mourning dove is not known to nest on the ground, but A. H. V. has found several nests on the ground, and I have personally found one thus placed, near Westville.

The double-crested cormorant is more common than indicated, for they are very frequently seen in autumn, every year, alighting on the spar-buoys near the Thimble Islands. One was shot at Short Beach, last fall, by Thos. E. Bradley. Leach's petrel is also more common than the list implies, for small flocks are seen off the Thimble Islands, nearly every year. A number of laughing gulls were seen at the same islands in 1912, by the writer and others. A Bonaparte's gull, with a broken wing, was taken alive at Outer Island, Oct. 23, 1913, by the writer.

The small white heron (white form of the little blue heron) seems to have become more common in recent years than indicated, for several have been taken at Pine Orchard, Durham, etc. The pine warbler is probably not so rare as indicated, for many have been seen in recent years. A. H. V. informs me that he and Dr. Bishop took a nest of Henslow's sparrow in Warren, June 8, 1900, which is not recorded, though one of the earliest records for this region.

It is to be regretted that the authors have not discussed the recent very alarming decrease in the numbers of many of our birds, especially the ducks. To those of us who occupy summer and autumn homes on the islands this is very notable. The old squaw, which appeared in large flocks of hundreds or thousands, in autumn, ten to fifteen years ago, has almost disappeared. During the last two years very few flocks were seen and those seldom contained more than half a dozen birds, often only two or three. The same is true of the white-winged scoter or coot, and other species, only in a somewhat less degree. The various shore birds have also notably decreased, as well as many of the small land birds. Possibly the extensive use of arsenical insecticides for spraying fruit and forest trees is largely responsible for the rapid decrease of some of the smaller birds, such as the catbird, oriole, robin, etc. A. E. V.

5. *Letters and Recollections of Alexander Agassiz, with a Sketch of his Life and Work, with portraits and other illustrations;* by G. R. Agassiz. Pp. 454, 8vo. Boston, 1913 (Houghton Mifflin Co.).—This work is of very unusual interest, for it gives a frank and realistic account of the life and work of one of the ablest and most remarkable men of our times, and one of the most successful. Mr. Agassiz was eminent, not only on account of his extensive and unequalled scientific expeditions, and his numerous publications in zoology and geology, but also as a skillful engineer and business man, who developed the great Calumet and Hecla copper mines from unpromising beginnings to great

and prosperous properties. His work at the mines was done in the early years, under very discouraging conditions and with many hardships.

The account of the strenuous life of Mr. Agassiz, in the first years of the development of the mines, reads like a real romance of pioneer life under adverse conditions of many kinds, and is of great interest. To many, the accounts of his home life, and that of his distinguished father, Louis Agassiz, will be among the most interesting parts of the book, for they are presented in an attractive way, that could be done only by a sympathetic member of his own family. Excellent, though brief, accounts are given of the numerous scientific expeditions carried out by Mr. Agassiz, to various parts of the world, but especially for deep-sea dredging and for the study of the principal groups of coral islands of the Pacific and Indian Oceans, and the West Indies. These, as is well known to all scientific men, resulted in vast additions to our positive scientific knowledge of the formation and growth of such islands, as well as to their zoology. Fortunately Mr. Agassiz had promptly published splendid reports on most of his explorations, though doubtless much remained to be done at the time of his death. This book also fittingly gives some adequate idea of the vast contributions made by Mr. Agassiz to the now great Museum of Comparative Zoology, not only in money, but also in time and labor, during the many years while he was Director and principal donor. In fact, it was mainly through him that the museum grew, in a few years, from comparatively small beginnings to one of the largest museums of the world. Many interesting letters to scientific friends, and to members of his family, are also reproduced. The book is a worthy tribute to a truly great man. A. E. V.

Obituary.

Dr. George William Hill, the eminent astronomer, died on April 16 at the age of seventy-six years. He was graduated from Rutgers College in 1859 and two years later took up work in the office of the American Ephemeris and Nautical Almanac. From 1898–1901 he was lecturer on celestial mechanics at Columbia University. His publications in astronomy and mathematics were numerous, and in 1905 a volume of collected mathematical works was issued; his Theory of Jupiter and Saturn was published in 1890. He was a member of many scientific societies and received several honorary degrees including that of Sc.D. from Cambridge, England, in 1892.

Professor George M. Minchin, since 1875 of the chair of mathematics in the Royal Indian Engineering College, Coopers Hill, died on March 16 at the age of sixty-eight years.

Dr. John Henry Poynting, professor of physics at the University of Birmingham, died on March 31 in his sixty-second year.

Dr. Antonino Salinas, professor of archæology at the University of Palermo, died on March 7 at the age of seventy-three years.

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CONTENTS.

Page

ART. XXX.—Reef Formations of the Northeast Coast of Brazil; by G. A. WARING. (With Plate IX) 367

XXXI.—Note on a New Meteoric Iron from Mount Edith, Ashburton District, West Australia; by W. M. FOOTE. 391

XXXII.—Occurrence of Molybdenum in Rocks with special reference to those of Hawaii; by J. B. FERGUSON..... 399

XXXIII.—Fruits of a Date Palm in the Tertiary Deposits of Eastern Texas; by E. W. BERRY 403

XXXIV.—Separation of Titanium from Iron, Aluminum, and Phosphoric Acid with the Aid of the Ammonium Salt of Nitrosophenylhydroxylamine ("Cupferron"); by W. M. THORNTON, JR. 407

XXXV.—New Features in the Geology of Northwestern Spitzbergen; by O. HOLTEDAHL..... 415

XXXVI.—Permian Geology of Northern Brazil; by M. A. R. LISBOA 425

XXXVII.—Finger Lake Bed in Ashland and Wayne Counties, Ohio, with Tilted Shore Lines; by G. D. HUBBARD 444

XXXVIII.—Remnants of an Old Graded Upland on the Presidential Range of the White Mountains; by J. W. GOLDTHWAIT 451

XXXIX.—The Shawangunk Conglomerate and Associated Beds near High Falls, Ulster County, New York; by T. C. BROWN..... 464

SCIENTIFIC INTELLIGENCE.

Chemistry and Physics—Peculiarity of Nickel and Cobalt Sulphides, A. THIEL and H. GESSNER: Dimethyl Phosphates of the Rare Earths, J. C. MORGAN and C. JAMES, 475.—Qualitative Chemical Analysis, A. VORISEK: Introduction to Modern Inorganic Chemistry, J. W. MELLOR, 476.—Practical Methods of Organic Chemistry, L. GATTERMANN: Spectrography of Röntgen Rays, M. DE BROGLIE, 477.—Removal of the Photoelectric Effect of Potassium, HALLWACHS and WIEDMANN, 478.—Heat of Formation of Hydrogen from Hydrogen Atoms, I. LANGMUIR: Thermal Expansion of Quartz Glass, K. SCHEEL and W. HEUSE, 479.—Physics for Technical Students; Mechanics and Heat, W. B. ANDERSON: Natural Sources of Energy, A. H. GIBSON, 480.—Effect on the Propagation of Electric Waves of the Total Eclipse of the Sun, 21st August, 1914, 481.

Geology and Natural History—Manual of Petrographic Methods, A. JOHANNSEN, 482.—History of Land Mammals in the Western Hemisphere: Nomenclature of certain Starfishes, A. E. VERRILL, 483.—Birds of Connecticut, Bulletin No. 20, J. H. SAGE, L. B. BISHOP, and W. P. BLISS, 484.—Letters and Recollections of Alexander Agassiz, with a Sketch of his Life and Work, G. R. AGASSIZ, 485.

Obituary—G. W. HILL: G. M. MINCHIN: J. H. POYNTING: A. SALINAS, 486.

Smithsonian Institution. (U. S. Nat. Mus.)

VOL. XXXVII. JUNE, 1914.

Established by BENJAMIN SILLIMAN in 1818.

THE AMERICAN JOURNAL OF SCIENCE.

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FOURTH SERIES

VOL. XXXVII—[WHOLE NUMBER, CLXXXVII].

No. 222—JUNE, 1914.

Smithsonian Institution
JUN 2 1914
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NEW HAVEN, CONNECTICUT.

1914.

THE TUTTLE, MOREHOUSE & TAYLOR CO., PRINTERS, 123 TEMPLE STREET.

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AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

Art. XI.—*The Binary System MgO–SiO$_2$;* by N. L. Bowen and Olaf Andersen.

Introduction.

In the course of work on two supposed binary systems of which $MgSiO_3$ was one component, the writers have found that $MgSiO_3$ is unstable at its melting point and can itself be treated only as part of a binary system and not as a separate component. The supposed binary systems mentioned must therefore be treated as ternary systems and before proceeding to the study of our separate ternary systems we have worked out jointly the binary system MgO–SiO_2 which is common to both.

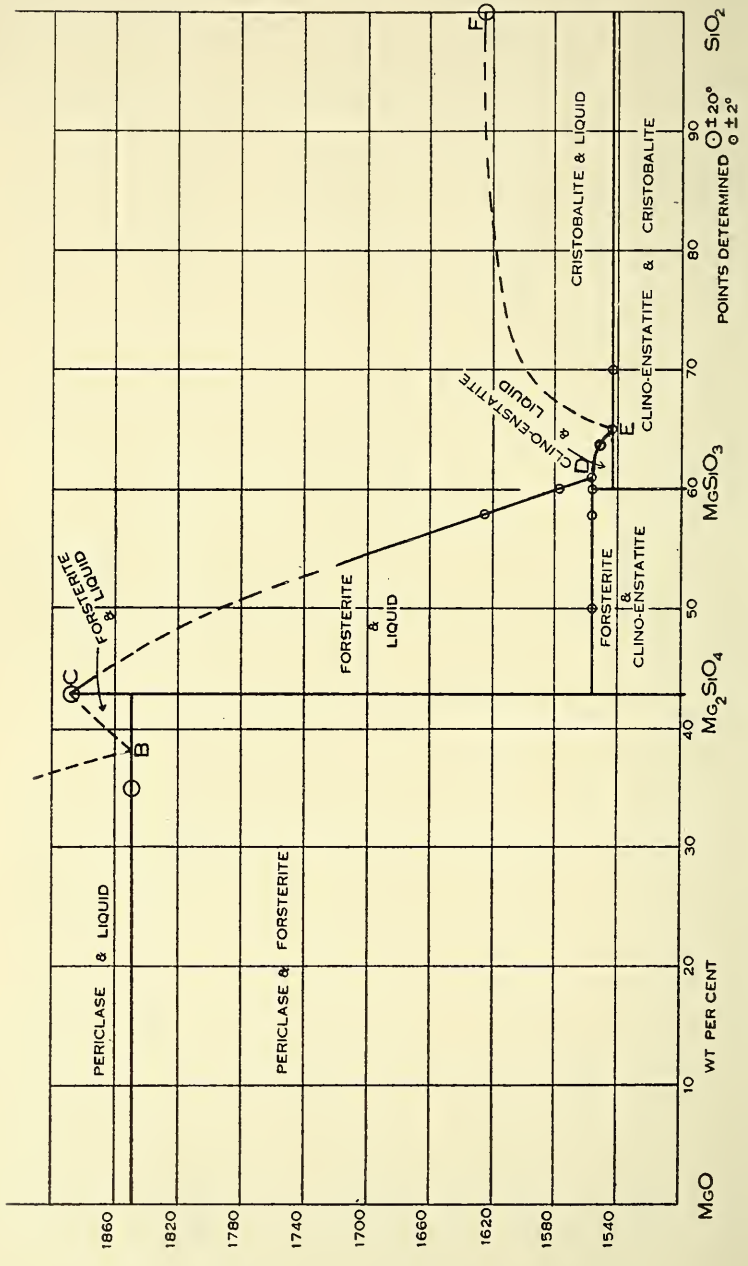
In compositions towards the magnesia end the temperatures are beyond the range of accurate determination and towards the silica end viscosity is so great as to preclude great accuracy, so that only approximate results are possible, but in the intermediate mixtures the determination of compounds and the fixing of the invariant points have been accomplished with precision.

The Method of Working.

The mixtures used were made up from selected quartz, ground and treated with HCl, and magnesia obtained by igniting the precipitated carbonate to constant weight.

In studying equilibrium in the system we have depended almost entirely on quenching experiments. The method has frequently been described in publications* from this laboratory. It consists in holding a small charge of a mixture of known composition at a measured temperature, in a platinum resistance furnace, until equilibrium is attained, then cooling

*e. g., Shepherd & Rankin, this Journal (4), xxviii, 308, 1909.


1860
1820
1780
1740
1700
1660
1620
1580
1540
MgO
10
20
30
40
50
60
70
80
90
SiO2
WT PER CENT
Mg2SiO4
MgSiO3
POINTS DETERMINED ⊙ ± 20° ○ ± 2°
PERICLASE & LIQUID
PERICLASE & FORSTERITE
FORSTERITE & LIQUID
FORSTERITE & CLINO-ENSTATITE
CLINO-ENSTATITE & CRISTOBALITE
CRISTOBALITE & LIQUID
CLINO-ENSTATITE & LIQUID
FORSTERITE & LIQUID
B
C
E
F

instantaneously to room temperature by allowing the charge to fall into a dish of mercury, and examining the charge under the microscope to determine the phases present. In this manner the phases present at all attainable temperatures, in all compositions, can be definitely fixed. The thermoelement of Pt–Pt : Rh, used to measure the temperature, is frequently calibrated by quenching charges of pure, artificial minerals of known melting point, usually diopside and anorthite. As will appear from an examination of the tabulated results, the actual procedure with any given mixture is to locate by quenching, between as narrow limits as possible, the temperature at which a phase appears or disappears.

To reach some of the higher temperatures an iridium furnace was used and the temperatures were measured optically.

Results.

The completed results are now presented in tabular and diagrammatic form before proceeding to their discussion.

Table I.

Quenching Results. Platinum Resistance Furnace. Temperature Measured with Thermoelement.

(a) *Liquidus of Forsterite.*

Oxides		Composition Compounds		Temperature	Time	Result
MgO	SiO_2	Mg_2SiO_4	11·7	1625°	1 hr.	glass and minute amount
42	58	$MgSiO_3$	88·3			forsterite
40·1	59·9	$MgSiO_3$	100	1576°	1 hr.	glass and forsterite
				1578°	1 hr.	glass only

(b) *Temperature of Invariant Point, Forsterite-Clino-enstatite-Liquid.*

50	50	Mg_2SiO_4	58·5	1555°	1 hr.	clino-enstatite and forsterite
		$MgSiO_3$	41·5	1559°	1 hr.	glass and forsterite
42	58	Mg_2SiO_4	11·7	1555°	1 hr.	clino-enstatite and forsterite
		$MgSiO_3$	88·3	1559°	1 hr.	forsterite and glass
40·1	59·9	$MgSiO_3$	100	1556°	1 hr.	clino-enstatite
				1558°	1 hr.	glass and forsterite

Temperature = 1557° ± 2°

(c) *Composition of Invariant Point, Forsterite-Clino-enstatite-Liquid.*

Oxides		Composition Compounds		Temperature	Time	Result
MgO	SiO_2	$MgSiO_3$	97	1557°	1 hr.	glass only
38·8	61·2	SiO_2	3	1555°	1 hr.	glass and clino-enstatite

Composition Oxides		Compounds		Temperature	Time	Result
MgO	SiO_2	$MgSiO_3$	97·5	1558°	1 hr.	glass only
39	61	SiO_2	2·5	1556°	1 hr.	glass and clino-enstatite
39·2	60·8	$MgSiO_3$	98	1560°	1 hr.	glass only
		SiO_2	2	1558°	1 hr.	glass and forsterite

Composition = $MgSiO_3$ 97·5%, SiO_2 2·5%

(d) *Temperature and Composition of Eutectic Clino-enstatite-Cristobalite.*

MgO	SiO_2	Compounds		Temperature	Time	Result
36	64	$MgSiO_3$	90	1540°	2 hrs.	Clino-enstatite and cristobalite
		SiO_2	10	1545°	2 hrs.	Clino-enstatite and glass
35	65	$MgSiO_3$	87·5	1542°	2 hrs.	Clino-enstatite and cristobalite
		SiO_2	12·5	1544°	2 hrs.	glass only
30	70	$MgSiO_3$	75	1540°	2 hrs.	Clino-enstatite and cristobalite
		SiO_2	25	1545°	2 hrs.	glass and cristobalite

Temperature = 1543° ± 2°
Composition = $MgSiO_3$ 87·5%, SiO_2 12·5%

(e) *Liquid of Clino-enstatite.*

MgO	SiO_2	Compounds		Temperature	Time	Result
38·8	61·2	$MgSiO_3$	97	1557°	1 hr.	glass only
		SiO_2	3	1555°	1 hr.	glass and clino-enstatite
36	64	$MgSiO_3$	90	1554°	2 hrs.	glass only
		SiO_2	10	1550°	2 hrs.	glass and clino-enstatite

Observed in Iridium Furnace.
Temperature Measured with Optical Pyrometer.

Oxides		Compounds		Temperature
MgO	SiO_2	Mg_2SiO_4	100%	melting point 1890° ± 20°
57·2	42·8			
65	35	Mg_2SiO_4	86	eutectic melting 1850° ± 20°
		MgO	14	

Summary of Invariant Points.*

Solid Phases		Liquid Phase		Temperature
Periclase	(MgO)	MgO	100 %	2800° (Kanolt)
Periclase	(MgO)	< 14% MgO		1850° ± 20°
Forsterite	(Mg_2SiO_4)	> 86% Mg_2SiO_4)		
Forsterite	(Mg_2SiO_4)	Mg_2SiO_4	100 %	1890° ± 20°
Forsterite	(Mg_2SiO_4)	$MgSiO_3$	97·5%	1557° ± 2°
Clino-enstatite	($MgSiO_3$)	SiO_2	2·5%	
Clino-enstatite	($MgSiO_3$)	$MgSiO_3$	87·5%	1543° ± 2°
Cristobalite	(SiO_2)	SiO_2	12·5%	
Cristobalite	(SiO_2)	SiO_2	100 %	1625° (Fenner)

* These points are, of course, invariant only when the system is considered as a condensed system.

Discussion of Results.

Magnesia.—We have found magnesia in only one form, as isotropic crystals corresponding with the mineral periclase. When it occurs embedded in glass, it is always in rounded grains with crystal outline at best only suggested. We have not tried to determine its melting point. Kanolt places it at 2800° C.;* Ruff, above 2500°.†

Silica.—Silica occurs in contact with liquid in magnesia-silica mixtures only as cristobalite. The inversion temperature cristobalite-tridymite, 1470°,‡ lies below the range of temperatures at which any of our mixtures are liquid. We have taken Fenner's value 1625° as the melting point of cristobalite.

Compounds.—There are two binary compounds, the orthosilicate, Mg_2SiO_4, and the metasilicate, $MgSiO_3$. We have not found any compounds, corresponding with the lime-silica compounds, åkermanite and tricalcium silicate, or traces of any phase other than the metasilicate, the orthosilicate and the end components, occurring in contact with liquid in the binary system.

Mg_2SiO_4.—Magnesium orthosilicate occurs in orthorhombic crystals corresponding with the natural mineral forsterite. The melting point of forsterite was determined in an iridium furnace, the temperature being measured by means of an optical pyrometer of the Holborn-Kurlbaum type. The pyrometer was calibrated for the known points: 2050°, melting-point of Al_2O_3;§ 1755°, melting-point of platinum; 1557°, dissociation (with melting) of $MgSiO_3$. The lamp-filament was matched against a piece of thin iridium foil lying on the surface of the charge of the powdered mineral contained in an iridium boat. On the occurrence of melting, movement of the foil is observed. By this method the melting-point of forsterite was found to be 1890°. The error of a measurement made in this manner may be as much as 20° or 25°, an accuracy very much less than that attained for points lying within the temperature range of the platinum furnace and Pt–Pt : Rh thermoelement ($\pm 2°$). We have therefore distinguished on the diagram the points determined by these two methods, indicating the latter by small circles and the former by larger circles.

$MgSiO_3$.—Magnesium metasilicate has no true melting point, i. e., there is no temperature at which the solid $MgSiO_3$ is in equilibrium with liquid of its own composition. The thermoelement records a strong absorption of heat at 1557° and this temperature has heretofore been considered the melting point, but quenching has shown that 1557° is the temperature of dissociation of $MgSiO_3$ into forsterite and liquid in the propor-

* Kanolt, C. W., Bureau of Standards, Reprint No. 212, 19, 1913.

† Ruff, O., Zs. anorg. Chem., lxxxii, p. 373, 1913.

‡ Fenner, C. N., The Stability Relations of the Silica Minerals, this Journal (4), xxxvi, 337, 1913.

§ Kanolt, C. W., Bureau of Standards, Reprint No. 212, 19, 1913.

tions, forsterite 5·5 per cent, liquid 94·5 per cent. The temperature must then be raised to 1577° before the solution of forsterite is complete and the whole becomes liquid.

Magnesium metasilicate was studied formerly at this laboratory and four forms described, the stable monoclinic pyroxene clino-enstatite, and three monotropic forms described as orthorhombic pyroxene, orthorhombic and monoclinic amphibole.* Later another orthorhombic form termed a-$MgSiO_3$ was added and described as enantiotropic with clino-enstatite (β-$MgSiO_3$), the latter being the low temperature form and the inversion point about 1365°.† The present work does not add any new information concerning the monotropic forms mentioned, but, concerning the material called a-$MgSiO_3$ a revision of the former statements is necessary in the light of the completed results of the binary system.

If a mixture of composition $MgSiO_3$ is cooled from the liquid condition, forsterite first separates out and with further cooling the remaining liquid crystallizes to a mixture of silica and $MgSiO_3$. The product then consists of clear, strongly-birefringent grains of forsterite embedded in a dusty matrix of indefinite properties, the dusty appearance being caused by the tiny specks of silica of very low refraction dotted through the $MgSiO_3$. It was these clear, strongly-birefringent grains of forsterite which were described as a-$MgSiO_3$ and were considered to be the product of inversion of clino-enstatite at a high temperature. They were really the product of dissociation of clino-enstatite at a high temperature and were not, as we have pointed out, a form of the metasilicate, but were the orthosilicate, forsterite.

The measured crystals described as a-$MgSiO_3$‡ and showing the forms (010), (110) and (011), referred to the axes $a : b : c = 1{\cdot}19 : 1 : 0{\cdot}47$ should have been termed forsterite. A rotation of the crystals through 90° on the b axis will give the forms (010), (021) and (110) referred to the axes $a : b : c = 0{\cdot}47 : 1 : \frac{1{\cdot}19}{2}$. These latter ratios are those of forsterite, within the errors of measurement, and the forms are common in that mineral.§ The form (010) is more prominent than is usually the case in larger crystals, but there is a well-recognized tendency in small and quickly formed crystals toward special development parallel to the plane of the best cleavage and we have observed this tendency in crystals of artificial forsterite.

* Allen, Wright and Clement, Minerals of the Composition $MgSiO_3$, this Journal (4), xxii, 388, 1906.

† Allen, White, Wright and Larsen, Diopside and its Relations to Calcium and Magnesium Metasilicates, this Journal (4), xxvii, 1, 1909.

‡ Allen, White, Wright and Larsen, this Journal (4), xxvii, 31, 1909.

§ See artificial crystals of forsterite, Allen, Wright and Clement, this Journal (4), xxii, 391, 1906.

The cleavage noted as parallel to (100) becomes, on rotation of the crystal, parallel to (001), which in natural forsterites, unlike other olivines, is the second best cleavage.* To this cleavage (// 001) the plane of the optic axes is parallel in the measured crystals, and here again there is correspondence with forsterite. In crystallographic properties, including the axial ratios themselves, in refractive indices, and in the relation between the position of the optical ellipsoid and crystallographic directions, the crystals called a-$MgSiO_3$ correspond with forsterite. The only supposed difference remaining is in the measured value of the optic axial angle. In view of the possible disturbance due to a slight strain in the crystals this minor difference noted in the former measurements cannot be regarded as establishing a species, in the face of the identity of the more distinctive properties with those of forsterite and of the proof by means of quenching that material so obtained must contain forsterite.

In the table below, the degree of correspondence is shown between the constants given for the crystals which were called a-$MgSiO_3$, after rotation through 90° on the b axis, and the values noted for artificial crystals of forsterite in an earlier publication from this laboratory, already referred to.

It was a difficult matter to identify the clear grains in the dusty material as originally prepared, but, by quenching, identical material can be prepared in two steps which make

Table II.

	Forsterite	"a-$MgSiO_3$"
Crystal system	orthorhombic	orthorhombic
Axial ratios	0·463 : 1 : 0·584	0·47 : 1 : 0·59
Forms observed	010, 021, 110 and others	010, 021, 110
Cleavages	// 0 10	not noted (crystals tabular // 010)
	// 001	// 001
Axial plane	// 001	// 001
Refractive indices	$a = 1{\cdot}645 \pm {\cdot}003$	$a = 1{\cdot}641 \pm {\cdot}003$
	$\gamma = 1{\cdot}668 \pm {\cdot}003$	$\gamma = 1{\cdot}663 \pm {\cdot}003$
Optic axial angle	86°	60°

the relations clear. A mixture of composition $MgSiO_3$ may be held at the temperature 1560°, a little above the dissociation point, and then quenched. The product consists of clear grains embedded in glass and the properties of these grains are definitely those of forsterite. Moreover, corresponding with

* It appears that in artificial forsterite cleavage after (001) may sometimes be as good as after (010), for Wright notes "cleavage perfect after (001) and (010)" for crystals of forsterite made in a flux.

the deficiency of silica in the forsterite there is an excess silica (above the composition $MgSiO_3$) in the glass as revealed by the fact that the refractive index of the glass, 1·575, is definitely lower than that of $MgSiO_3$ glass, 1·580. If this material is returned to the furnace at a lower temperature and crystallized, the product consists of clear forsterite grains surrounded by dusty material ($MgSiO_3$ and silica), the whole precisely the same as the material obtained in one step by cooling from the liquid state. On the other hand, a clear, forsterite-free, $MgSiO_3$ glass, which can be obtained only by quenching from a temperature above 1577°, may be crystallized at any temperature between 1200° and 1557° and the product is only clean clino-enstatite, without the strongly-birefracting forsterite grains which were called *a*-$MgSiO_3$ and without the dusty appearance (silica). This clino-enstatite may be held for an indefinite period at any temperature up to 1557° without showing any tendency to invert to another form.

It should be noted, moreover, that this method of holding the mixture $MgSiO_3$ above 1577°, then quenching and crystallizing the glass below 1557°, is the *only dependable method* of obtaining pure clino-enstatite free from forsterite and silica, though *occasionally* the melt can be cooled quickly enough in the furnace, through the range 1577°–1557°, to avoid the crystallization of forsterite. The occasional non-appearance of the material called *a*-$MgSiO_3$ in the earlier work is due to this latter fact.

In summary, then, it may be stated that there is no enantiotropic inversion of clino-enstatite into *a*-$MgSiO_3$. The substance which was called *a*-$MgSiO_3$ is the product, not of inversion of clino-enstatite, but of dissociation of clino-enstatite and is the mineral forsterite, Mg_2SiO_4.

Since we are dealing with equilibrium, the form clino-enstatite is the only form of $MgSiO_3$ which appears on our diagram. It always occurs in the characteristically twinned form described in former publications and in the optical part of this paper.

The Eutectic, Periclase-Forsterite.—The melting temperatures of all mixtures of MgO and Mg_2SiO_4 are beyond the range of the platinum resistance furnace used for most of the work, but we studied one mixture between these two in order to decide the presence or absence of a eutectic point. Silica and magnesia were mixed in the proportion to give Mg_2SiO_4 86 per cent, MgO 14 per cent, and ground together and the material heated for half an hour at about 1600°. Grinding and heating were repeated and then the material was examined. It proved to be clearly a fine-grained mixture of forsterite and periclase and gave no trace of any compound intermediate between these two. A small charge of this mixture was then

carefully heated on a small piece of platinum foil in the oxy-hydrogen flame. The mixture melted about the same time as the platinum and as the edge of foil melted away, the liquid silicate ran back upon the still unmelted portion and was thereby saved for examination. The larger of the liquid globules recrystallized on removal from the flame to a mixture of forsterite and periclase, both well crystallized. Some of the more quickly cooled material, however, consisted of periclase and glass, indicating that the composition dealt with lies on the magnesia side of the eutectic.

The behaviour of this mixture was then examined in the iridium furnace, after the manner of the determination of the melting-point of forsterite. The mixture became liquid at 1850°, 40° below the melting point of forsterite. The diagram has been drawn in accordance with these results, showing a eutectic between forsterite and periclase at 1850° and with the composition close to forsterite (less than 14 per cent MgO). The determination of the composition of the eutectic is, of course, the roughest approximation.

The Liquidus between Mg_2SiO_4 and $MgSiO_3$.—Points on the liquidus between Mg_2SiO_4 and $MgSiO_3$ were determined up to a temperature of 1626° by means of the thermoelement, Table I (a). Above this temperature no points were determinable except the melting point of forsterite itself (1890°).

The Invariant Point, Forsterite-Clino-enstatite-Liquid.—Between forsterite and clino-enstatite there is no eutectic, for the reason that clino-enstatite itself is unstable at its melting point, breaking up into forsterite and liquid. The composition of the liquid capable of existing in contact with both clino-enstatite and forsterite (D) was fixed in the following manner: Its composition was first approximately determined by holding a charge of $MgSiO_3$ at 1560°, a little above the dissociation point, and quenching. The product consists of forsterite crystals and glass and the refractive index of the glass was determined. The refractive index of pure $MgSiO_3$ glass is 1·580, that of the glass in the quenched product as obtained above was 1·575 ± ·001. From the indices of refraction of glasses of mixtures of $MgSiO_3$ and SiO_2 in known proportions the composition of this glass was found to correspond approximately with $MgSiO_3$ 97 per cent, SiO_2 3 per cent. Mixtures of various compositions close to this were then made up and the first crystal separating from them (primary phase) determined by quenching. In this manner it was found that in 3 per cent SiO_2 the primary phase was clino-enstatite, in 2·5 per cent SiO_2 clino-enstatite, and in 2 per cent SiO_2 forsterite. Thus the composition of the point D (fig. 1) was determined at 2·5 per cent SiO_2.

All mixtures of compositions lying between Mg_2SiO_4 and the

point D should break up when the temperature is raised to 1557° into a liquid of composition D and forsterite. We have confirmed this behaviour in several of these mixtures (see Table I (b)).

The Crystallization of Mixtures of Mg_2SiO_4 and $MgSiO_3$.—The crystallization of mixtures lying between Mg_2SiO_4 and $MgSiO_3$ takes place, when perfect equilibrium obtains, in the following manner: Forsterite crystallizes out first and increases in amount until the temperature 1557° is reached. At this temperature the liquid has the composition D and clino-enstatite begins to crystallize out, forsterite to redissolve, this process continuing until all the liquid is used up and the whole consists of forsterite and clino-enstatite. In pure $MgSiO_3$ the early separation of forsterite takes place in the same way, but at the reaction temperature (1557°) the last of the liquid and the last of the forsterite are used up at the same instant and the whole consists of clino-enstatite. In compositions between $MgSiO_3$ and the point D, forsterite separates first as before, at the reaction point it is completely resorbed, leaving clino-enstatite and some liquid. With further lowering of temperature clino-enstatite continues to separate until, at 1543°, when the liquid has the composition E, cristobalite separates also and the whole crystallizes at this temperature, giving a mixture of clino-enstatite and cristobalite.

Such is the behaviour of these mixtures when complete equilibrium is attained. We have already seen, however, that with quick cooling, equilibrium is not attained and a preparation of composition $MgSiO_3$ will then crystallize to a mixture of clino-enstatite, silica, and forsterite. The same fact is true of all mixtures lying between Mg_2SiO_4 and D, the reason being that with quick cooling the liquid of composition D, instead of reacting with (redissolving) forsterite at 1557°, simply crystallizes, as the temperature falls quickly below this point, to a mixture of $MgSiO_3$ and silica. Such mixtures containing both forsterite and silica are unstable but will persist indefinitely.

The Eutectic, Cristobalite-Clino-enstatite.—The eutectic point between cristobalite and clino-enstatite was located by quenching charges of various compositions to determine the primary phase. The composition $MgSiO_3$ 90 per cent, SiO_2 10 per cent shows clino-enstatite as the primary phase. The composition $MgSiO_3$ 87·5 per cent, SiO_2 12·5 per cent is completely crystalline at 1542° and completely liquid at 1544° and therefore corresponds sensibly with the eutectic composition. Cristobalite is the primary phase in mixtures richer in SiO_2 (see Table I (d)). The eutectic melting was observed at the same temperature (1543°) in mixtures on both sides of the eutectic.

In the mixtures on the silica side we were not able to determine the liquidus with great assurance on account of the high viscosity of the mixtures. There are, however, indications that

the liquidus is very steep close to the eutectic. It would then be very flat close to silica, if 1625° is the melting point of cristobalite.

Previous Work on the System Mg_2SiO_4–$MgSiO_3$.—A recent paper by Deleano presents the results of an investigation of the system Mg_2SiO_4–$MgSiO_3$.* Deleano found that all the compositions close to $MgSiO_3$ soften at the same temperature (within the error of measurement). These results are in accord with our determination that there is no eutectic between $MgSiO_3$ and Mg_2SiO_4 but a dissociation-temperature at which all compositions between D and forsterite (fig. 1) break up into liquid and forsterite, though Deleano presents a diagram showing a eutectic.

Deleano concludes, on the basis of finding periclase in a melt of forsterite composition, that forsterite is unstable at the melting-point. It is to be noted that the mixtures used were made up by mixing silica and a calculated weight of $MgCO_3.3H_2O$. This latter compound is very difficult to obtain free from basic carbonate, the presence of which would result in an excess of magnesia in the product.

We made the forsterite mixture, as we did our other mixtures, by mixing silica and magnesia in calculated proportions, the magnesia being obtained by igniting the precipitated carbonate to constant weight. When the mixture is so made and when perfect mixing is accomplished by repeated grinding and heating, the product may then be melted and crystallized repeatedly and the crystalline product is always pure forsterite without a trace of periclase.

Optical Study.

The product of each quenching experiment was examined in powder form under the microscope and the optical properties of the various phases determined. In this manner, not only the nature of the crystalline phases is noted, but, at times, the composition of the liquid phase may be obtained by determining the refractive index of the glass. The various optical constants were measured on suitable material and are recorded below.

Periclase.—Periclase was the only form of MgO noted. It occurs in the preparations, when embedded in glass, as rounded grains of isotropic character and index 1·73. We have also examined periclase made by the Norton Company by fusing magnesite. It is in coarse granular lumps showing the excellent cubic cleavage and the optical properties of periclase. The hardness of this material is about equal to that of apatite (5) and distinctly less than that of orthoclase (6).

* Zs. anorg. Chem., lxxxiv, 423, 1914.

Cristobalite.—Silica occurs in our melts only as cristobalite. As viewed under the microscope at room temperature the crystals are birefringent, α-form, but have the crystal form of the isotropic β-form in which they crystallized at the temperature of the furnace. When embedded in glass the crystals are sometimes sharply outlined octahedra, modified by the cube, but usually the cube is the more prominent form and the crystals are, by distortion, stout prisms due to slight elongation parallel to one of the cubic axes. The birefringence is barely discernible with the aid of the sensitive-tint plate, this apparently low value being probably due to the mutual compensation of a number of twinning lamellæ. Occasionally polysynthetic twinning was observed. The mean refractive index, $1{\cdot}485 \pm {\cdot}001$, agrees with the values found by Fenner.*

Forsterite.—We have found Mg_2SiO_4 only in the form corresponding with the natural mineral forsterite. Measured artificial crystals of this mineral are figured in a former publication from this laboratory.† Crystals from this same stock, prepared by fusing together magnesia, silica and magnesium chloride in an atmosphere of HCl, were used to determine the optical constants of forsterite more accurately. The acute angle of the unit prism was used as a wedge and the refractive indices α and β determined for sodium light on the goniometer, by the method of minimum deviation. The optic axial angle was then measured directly on the Wülfing apparatus in sodium light, the crystal being immersed in a liquid of index β. From these values the index γ was calculated. The results are given below:

$$\beta = 1{\cdot}651_0 \qquad 2V = 85^\circ\ 16' \pm 4'$$
$$\alpha = 1{\cdot}635_1 \qquad \gamma = 1{\cdot}670_4$$
$$\gamma - \alpha = {\cdot}035_3$$

The cleavage is distinct after (010) and (001).
The optical orientation is $c = \mathfrak{b}$ and $a = \mathfrak{c}$.

A determination of the density of these crystals was made in Rohrbach's solution by the flotation-refractive index method of Merwin.‡ The crystals used were small and were examined under the microscope and found free from inclusions of any kind. The density found was $3{\cdot}216 \pm {\cdot}002$.

Clino-enstatite.—With the exception of the occasional appearance of the monotropic amphibole form of $MgSiO_3$ in quickly cooled melts, the stable monoclinic pyroxene, clino-enstatite, was the only form of the metasilicate observed in our quenches.

* The Stability Relations of the Silica Minerals, this Journal, (4), xxxvi, 1913, 354.

† Allen, Wright and Clement, Minerals of the Composition $MgSiO_3$, this Journal, (4), xxii, 1906, 391.

‡ This Journal, (4), xxxi, 425, 1911.

We have therefore made no observations which throw further light on the relation between enstatite and clino-enstatite. The two are very similar in physical properties but clino-enstatite is monoclinic.

Clino-enstatite crystals have been measured and the figures given in a former publication of this laboratory. It has the characteristic, perfect prismatic cleavage of the pyroxenes. Usually rough cracks //(001) show as well. Polysynthetic twinning after (100) is exceedingly characteristic. The plane of the optic axes is normal to (010) as would be the case in enstatite if it were oriented after the manner of the monoclinic pyroxenes. Sections //(010) do not, therefore, show the highest interference colors as in most pyroxenes. The angle $C \wedge c = 22°$. The optic axial angle is difficult to measure on account of the polysynthetic twinning. Wright and Larsen give the value 53·5°.* The refractive indices were determined on material crystallized from a clear glass and therefore free from inclusions of silica, which tend to give a value slightly too low. The results were $\alpha = 1{\cdot}651 \pm {\cdot}001$, $\gamma = 1{\cdot}660 \pm {\cdot}001$ determined by immersion in liquids of known refractive index.

Bearing of the Results on Petrologic Problems.

In the chemically pure products described it has been shown that, over a wide range of compositions, the olivine, forsterite, crystallizes out and is later either partly or completely redissolved, reacting with the liquid to give the pyroxene, clino-enstatite. This resorption takes place as a necessary result of equilibrium and during the normal course of crystallization. In natural rocks the resorption of olivine and the formation about the olivine crystals of reaction-rims of enstatite has often been noted.† Such reaction between the crystals in a magma and its still liquid portion has sometimes been assumed to imply some drastic change of conditions such as the sudden relief of pressure. It has also been considered possible that such crystals may have sunk into magma of such a composition that they became unstable. In the case of olivine it is probable that such assumptions are unnecessary. Olivine crystals may perhaps be partly or wholly resorbed during the normal course of crystallization as a simple result of cooling, as in the case of the more simple mixtures described.

It has been shown also that certain crystalline products, when quickly formed, may contain forsterite and free silica (cristobalite) together and this condition may persist indefinitely although it does not represent equilibrium. Dr. Cross‡ has found cristobalite in cavities of olivine-bearing lavas from

* This Journal, (4), xxvii, 30, 1909.

† Harker, A., Natural History of Igneous Rocks, p. 269.

‡ Personal communication.

Hawaii, but in that case we are probably dealing with a quite different matter, perhaps with the decomposition of silicates and the setting free of silica as cristobalite by the action of vapors.

A mixture of total composition $MgSiO_3$ 98 per cent, SiO_2 2 per cent, can be cooled in such a manner that it consists of forsterite and glass. We have then what might be termed an olivine-bearing lava in simplified form, though the actual total composition of the mixture shows no olivine but an excess of free silica. This simple case emphasizes the fact that, in spite of the great usefulness of a purely chemical classification of rocks, a classification in terms of the actual phases (minerals) present is extremely desirable because these phases are an expression of equilibrium under the conditions of their formation.

Summary.

Equilibrium in the binary system MgO–SiO_2 was studied by applying the method of quenching.

There are two compounds, the orthosilicate Mg_2SiO_4 and the metasilicate $MgSiO_3$, capable of existing in contact with liquid in the binary system. The former crystallizes in a form corresponding with the mineral forsterite and the latter forms crystals similar to enstatite in most properties but of monoclinic symmetry, clino-enstatite.

Clino-enstatite is the only stable form of $MgSiO_3$ encountered. It has no true melting-point but breaks up at 1557° (formerly considered the melting-point) into forsterite and liquid and the temperature must be raised to 1577° before complete solution of the forsterite takes place.

In an earlier publication from this laboratory, crystals termed α-$MgSiO_3$ were described as a high-temperature form of magnesium metasilicate. They were considered to be the product of inversion of clino-enstatite (β-$MgSiO_3$), but the crystals described have now been proved to be a product of the dissociation at 1557° and to be the orthosilicate, forsterite, not a form of the metasilicate.

On account of the break up of clino-enstatite into forsterite and liquid there is no eutectic between the two compounds, and the liquids show, on cooling, the partial or complete re-solution of forsterite at the reaction point, 1557°, the liquid reacting with the forsterite crystals to give clino-enstatite.

A discussion is given of the geological significance of this resorption of the olivine, forsterite, by reaction with the liquid to give the pyroxene, clino-enstatite.

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Art. XLI.—*An Application of the Displacement Interferometer to the Horizontal Pendulum;** by C. Barus.

1. *Introductory.*—The displacement of ellipses or of interference lines in the spectrum is probably capable of being photographed for continuous registry, though less easily than the motion of a spot of light. At all events, it seemed interesting to endeavor to register the excursions of the horizontal pendulum by displacement interferometry, not so much with a view to recording seismological phenomena as to approach by this means certain other problems as, for instance, the tilting of the earth's surface relatively to the plumb line, the measurement of the constant of gravitation, etc. The present paper, therefore, undertakes a new departure with this special end in view, with possibly some ulterior bearing on microseismology.

If the inclination of the axis of the horizontal pendulum is but a few degrees to the vertical and a large framework is in question (there is scarcely any limit to size other than strength of the material), the sensitiveness of the apparatus, when the excursions are read off in terms of light waves, is astonishing; or at least, it would be so, if the instrument supplied with mirror and screen had not been so thoroughly perfected. The horizontal pendulum, moreover, has this peculiarity, that it is able to support relatively large weights; *i. e.*, relatively massive bodies may be subjected to each other's attraction.

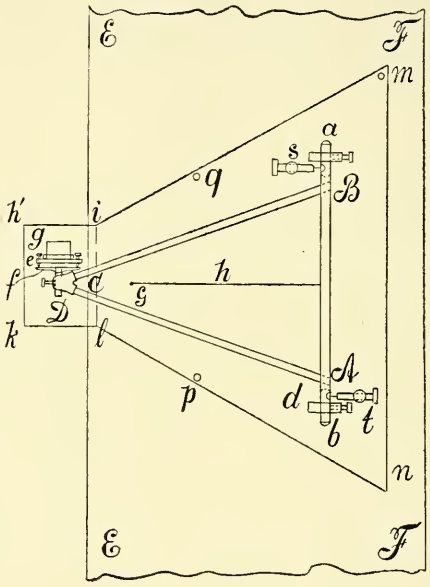
2. *Apparatus.*—The horizontal pendulum has the usual form of a swinging gate and was constructed of 3/8 inch (vertical) and 1/4 inch (oblique) thin steel tubes. The material available here was unfortunately slightly too thick-walled, a defect which will be modified in the future. Moreover, steel, as has been seen in the work with the electrometer, is an undesirable metal in the varying magnetic field of a city, when the micrometry of angles is in question.

The frame of the pendulum, as shown in fig. 1, is very simple. ABC is the truss of steel tube, soldered at A and B and terminating in the brass clutch at C, into which it is also soldered. The tube AB is slotted at top and bottom and each end receives a solid cylinder a and b of glass-hard steel, snugly. These are held in place by collars c and d. The cylinder b contains a conical socket to receive the point of the steel pivot t, a portion of the tube A having been removed at this part. Similarly the cylinder a contains a vertical slot (or reëntrant dihedral edge) to receive the pivot s. These pivots are ad-

* Abridged from a forthcoming Report to the Carnegie Institution in Washington.

justable toward and from the rear, from right to left, and each is revolvable about a horizontal axis normal to the figure, in a way which will presently be shown. The distance between pivots was 97 centimeters, the distance between the cylinders AB and D about 111 centimeters, and the reduced end projects about 16 centimeters beyond the edge EE of the brick pier to which the pivots are attached. D, clutched by C, is

Fig. 1.



the hollow stem of the tablet f, which holds the plane dot slot arrangement to secure the grating g, a spring passing down the interior of the tube D. The lower pivot should preferably point towards the center of gravity, G.

The whole apparatus is enclosed in a more or less triangular flat case $h'mnk$, firmly bolted to the wall at q, m and p. The two sides of the case beyond the pier, $h'ilk$, may be slid off to the left, and then the whole remainder lifted off its bearings without touching the pendulum, as the case has no rear wall. The front face is within three inches of the face of the pier. This arrangement was found very satisfactory. The head of the case ki is of course glass faced (identical plates) in front and rear, so that the grating, etc., may be seen. A convex mirror if placed at g reflects a beam of light showing the pendulum to be nearly stationary during the day, in spite of

the surrounding city. The slow normal variations were not greater than 5 millimeters on a radius of 13 meters, corresponding therefore to about 40 seconds of arc. The corresponding change of inclination relative to the plumb line would be less than 1/100 of this, depending on the period given to the horizontal pendulum.

The mass of the pendulum was 720 grams; that of the grating holder originally 475 grams, and of the grating, etc., about 55 grams, making a total of 1250 grams; but these masses are to be much modified in the future. The center of gravity, at G, with the grating in place, was originally about 80 centimeters from the axis AB.

Fig. 2.

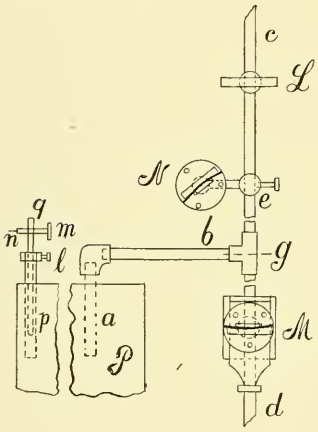
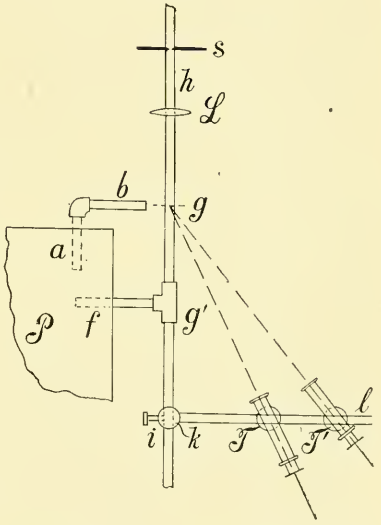


Fig. 3.



The grating at g moves between the two opaque mirrors (fig. 2) usually called M and N of the displacement interferometer, in the way shown in my earlier work* on interferometry.

But these mirrors M and N must in the present case be identically *concave*, silvered on their front faces, and at a distance equal to their common radius of curvature from the center of the ruled face of the grating. This center is illuminated by the impinging beam of light from the collimator, and the returned beams, reflected from M and N, must pass through the same area of illumination. In such a case the reflection at M and N is always normal to those surfaces and the rotation

* See Carnegie Publications, No. 149.

of the grating does not interfere with the definition of the ellipses of the interference pattern. For any other distance of M and N except these radii of curvature, the spectra in the telescope will cease to coincide horizontally on rotating the grating and the ellipses would at once vanish. On the other hand, the displacement of the grating *in arc* at the end of the arm of the horizontal pendulum, is registered in amount by the shifting of the ellipses in the interfering spectra. This displacement includes of course (as a small correction) the additional thickness of glass introduced by the rotation of the grating. The displacement in question is the arc, which, when referred to the axis of the horizontal pendulum, measures its angular deviation resulting from the inclination of the earth's surface relatively to the plumb line.

It is convenient to exhibit the details of the instrument (figs. 2 and 3) in separate parts for convenience in drawing, these being superimposed in practice.

Fig. 2 shows the attachment of the two concave mirrors M and N of the interferometer to the pier P. Here *abcd* is an ordinary framework of 1/4 inch gas pipe. The end a is firmly plastered into the pier, b rises at a slight angle, cd being horizontal and parallel to the pencil of light from the slit, while g shows the position of the grating on the horizontal pendulum in fig. 1. The arm b lies below the case in that figure and is free from it. Each of the mirrors M and N is on plane dot slot adjustments, and M is provided with a Fraunhofer micrometer suggested in the figure. Both M and N can be rotated around horizontal and vertical axes for adjustment, the former, M, being provided with a fine motion. The clutch e and the corresponding one for M (not shown) allow the micrometer to be placed at a greater or less distance from the grating. The center of the mirror is about on the same horizontal level as the grating. It is also usually convenient to place the lens L of the collimator in its screen, on the same rod cd, with an appropriate clutch and rack and pinion.

The complementary frame work is shown in fig. 3 and holds the slits of the collimator (or the filament of a Nernst lamp) and the two telescopes T and T' in place for observation, T being used for the direct slit image and T' for the diffraction spectra and interferences. The frame *fghi* is as before of gas pipe, f being firmly plastered into the wall on the front face of the pier (the other one, ab, being on the side). The telescopes T and T' are necessarily adjustable on a horizontal and vertical axis, may be raised and lowered and moved right and left along the rod kl, held by a firm clutch at k. The lens L may also be carried on ab, as has been stated. Right and left, up

and down motion is needed for the insertion of these appurtenances. The rods *cd* and *hi* are not in the same horizontal or the same vertical plane, so that the systems may be superposed as stated.

In the course of the work it appeared, however, that the framework of simple pipe was annoyingly subject to tremors. It was found necessary to lengthen the rods *gd* and *gc*, *g'i* and *g'h* to over a meter in length. Hence it was preferable to bolt the pairs of parallel rails together for increased stiffness and to secure the ends of each pair with a wide *tetrahedral* brace of gas pipe, abutting at the pier, against horizontal and vertical displacement. So adjusted, the system was light and rigid and easily modified for the different purposes of the experiment. The additional braces have not been shown in the figure, as they depend on purely local conditions, the base of each tetrahedron being at the pier and its apex at the corresponding common ends of the pairs of rails, *gc* and *g'h*, *gi* and *gd*. All appurtenances like lenses, mirrors, micrometers, are attached with strong removable clamps, provided where needed with rack and pinion attachment for focussing, etc. This allows of an easy and indefinite modification of the system and is thus very convenient for experimental purposes of the present kind. Finally the telescopes T and T' are preferably supported on an independent tripod resting on the floor, the arm *kl* being removed. It will be remembered that the sodium line of the spectrum and not the vertical crosshairs of the telescope is used for reference.

It is finally necessary to describe the pivots of the horizontal pendulum, and these are also given in fig. 2. Here p is a length of 1/4 inch gas pipe fixed in the wall with plaster. The outer end is split lengthwise and carries a collar and set screw l, so that the brass rod q fitting the pipe p snugly may be firmly secured. The end of q carries the horizontal very snugly fitting screw m of 1/4 inch brass, which is tipped at n with the steel point of a darning needle. The point of n is received by the socket of the horizontal pendulum. Thus n may be rotated about qp and moved fore and aft or right and left, for adjustment. The socket is a conical hollow of about 60° in glass hard steel.

3. *Equations.*—With regard to the apparatus just described, the size of which was limited to conveniently fit the given pier, the following equations may be used to obtain an estimate of the sensitiveness to be expected:

Let ϕ be the inclination of the axis of the pendulum to the vertical and θ an angular excursion of the pendulum, measured from its position of equilibrium. Let h (fig. 1) be the

normal distance of the center of gravity from the axis. The rise of the latter above its lowest position is

$$y = h\,(1 - \cos\theta)\,\sin\phi = 2h\,\sin\phi\,\sin^2\frac{\theta}{2} \qquad (1)$$

and the energy potentialized, if the total mass is M, will be

$$W = 2Mgh\,\sin\phi\,\sin^2\frac{\theta}{2} \qquad (2)$$

which for small displacements corresponds to the torque Fh, at the angle θ. This torque is

$$\frac{\partial W}{\partial\theta} = Mgh\,\sin\phi\,\sin\theta = Mgh\,\phi\theta, \qquad (3)$$

nearly; whence, the total force F acting at the center of gravity, or F/M per gram of mass M, is

$$\frac{F}{M} = g\phi\theta \qquad (4)$$

In the above apparatus $M = 1245$ grams, $h = 80$ centimeters. Hence per vanishing interference ring, *since the grating moves*, if ΔN is the displacement of the micrometer to bring back the center of ellipses to the fiducial sodium line

$$\theta = \frac{\Delta N/2}{R} = \frac{\Delta N}{2R} \qquad (5)$$

where R is the distance of the point of the grating at the line of light corresponding to the slit, from the axis of rotation. In the apparatus $R = 111$ centimeters. Hence the angle corresponding to a vanishing ring is, since $\Delta N = 30 \times 10^{-6}$,

$$\theta = \frac{30 \times 10^{-6}}{2 \times 111} = 13 \times 10^{-8}\ \text{radians} = \cdot 028''$$

Furthermore if $\phi = 1^\circ = \cdot 0175$ radians

$$F/M = 981 \times \cdot 0175 \times 13 \times 10^{-8} = 2{\cdot}3 \times 10^{-6}\ \text{dynes}$$

per vanishing ring, per gram mass at the center of gravity of the pendulum.

The total pull of the center of gravity of the above pendulum is thus

$$F = 2{\cdot}3 \times 10^{-6} \times 1245 = 2{\cdot}9 \times 10^{-3}\ \text{dynes}$$

per vanishing ring, on one side. By lengthening the radius from h to R this may be decreased to about 2×10^{-3} or less. Hence in case of gravitational attraction at one centimeter of

distance it would require two equal masses m (since $\gamma = 6{\cdot}7 \times 10^{-8}$ roughly) of 180 grams, per vanishing interference ring, at a distance of 1 centimeter. These conditions could be supplied by using parallel plates. On the other hand, the framework of the above pendulum is unnecessarily heavy, and was constructed out of the material at hand. It could easily be reduced in weight much below the above datum, or the greater part supported on a float, so that the case is to be stated many times more favorably.

Resuming equation (3), if K is the moment of inertia, i the radius of gyration, and T the period and l the length of the horizontal pendulum,

$$T = 2\pi i \sqrt{\frac{1}{gh\phi}}. \tag{6}$$

an equation from which ϕ may be found in terms of T, i, and h, which must be measured.

Again the indicated length H of the pendulum (distance from the center of gravity to the point of intersection of the axis and the plumbline through the center of gravity) is

$$H = h/\sin\phi = h/\phi, \text{ nearly.} \tag{7}$$

The change of vertical inclination α of the axis of the pendulum corresponding to the horizontal deviation θ is then, nearly,

$$\alpha = \frac{h\theta}{H} = \theta\phi, \text{ nearly;} \tag{8}$$

or if the period T be introduced from (6) and θ from (5)

$$\alpha = \frac{4\pi^2 i^2}{T^2 hg} \frac{\Delta N}{2R} \tag{9}$$

It is in equation (8) that the condition of remarkable sensitiveness resides. Thus, if the interferometer is used,

$$\alpha = \phi\Delta N/2R,$$

and, if $\Delta N = 30 \times 10^{-6}$ and $\phi = 10^{-2}$ (somewhat less than 1° of arc), $R = 111$ cm., as above,

$$\alpha = 13 \times 10^{-10} \text{ radians} = {\cdot}00028''$$

per vanishing interference ring.

If F, as before, is the force at the center of gravity, the corresponding force at the grating, a distance R from the center, is

$$F_R = Mg\phi\theta \frac{h}{R} = M \frac{4\pi^2 i^2}{T^2 R} \theta \tag{10}$$

since ϕ is given by equation (6).

It is this equation which suggests itself for the measurement of the constant of gravitation which thus depends on quantities all easily measurable. It implicitly contains h, since i refers to an eccentric axis and $i^2 = i_0^2 + h^2$; but i may be found directly.

The deviation θ is given by (5). If, however, the device* of two parallel mirrors, equisdistant (distance R) from the axis of the horizontal pendulum, be used, and if light impinges on either mirror at an angle of incidence I (the impinging and reflected beams being always parallel),

$$\theta = \frac{\Delta N'}{2R \sin I} \tag{11}$$

where $\Delta N'$ is the displacement of the micrometer. The horizontal pendulum is in this case constructed symmetrically to the vertical axis in the form of a balance beam, but somewhat heavier on one side.

Finally, the compound pendulum may be supported on a cylindrical *float*, symmetrical to the vertical axis of the pendulum and submerged in water or some other liquid. In such a case, the mass of the compound pendulum may be reduced in any degree without serious difficulty from capillary forces, as will be shown elsewhere. Since the center of buoyancy is in the vertical axis of the horizontal pendulum, the above equation needs but slight alteration. Let V be the volume of the float, so that $V\rho g$ is the buoyancy. Apart from the temperature conditions, $\rho = 1$, and hence the above equations take the successive forms, since $(M - V)g$ is supported instead of Mg:

$$W' = \tfrac{1}{2}(M - V)gh\phi\theta^2 \tag{12}$$

$$T' = (M - V)gh\phi\theta \tag{13}$$

The force at a distance R from the axis is, when the center of gravity is at a distance h,

$$F_R' = ((M - V)g\phi h/R)\theta \tag{14}$$

Hence the force has been reduced in the ratio of $M/(M - V)$ for the same θ. One may also note that it is smaller, not only as ϕ is smaller, but as h/R is smaller. Hence a symmetrical form of pendulum, like the balance beam, but slightly heavier on one side, suggests itself for work on gravitational attraction, etc.

It was not found difficult to reduce the weight of the pendulum by flotation to 40 grams, *i. e.*, about 31 times. Hence the force per vanishing interference ring computed above would now be

* Barus, this Journal, xxxvii, p. 83 et seq., 1914.

$$F_R' = 2 \times 10^{-3}/31 = 6 \times 10^{-5} \text{ dynes, roughly.}$$

This would be equivalent to the attraction of two 30 gram weights at 1 centimeter of distance.

Furthermore,

$$T' = 2\pi i \sqrt{\frac{1}{gh\phi} \quad \frac{1}{1 - V/M}} \tag{15}$$

whence, since $\theta = \Delta N/2R$

$$F_R' = \frac{M}{R^2} \quad \frac{2\pi^2 i^2}{T'^2} \Delta N \tag{16}$$

all of which quantities are easily determined with accuracy. To find the radius of gyration i for instance, a body of known moment of inertia may be suspended at the end of the horizontal pendulum and the periods T of the pendulum before and after the suspension determined, with or without the float.

Finally the change of vertical inclination α becomes, ϕ being given by (15),

$$\alpha = \frac{h\theta}{H} = \theta\phi \text{ (nearly)} \tag{17}$$

If the pendulum is damped, which will usually be the case, it may be necessary to observe the logarithmic decrement, in order to compute the free period in the usual way.

If the end of the horizontal pendulum is loaded with the weight m of a disc at a mean distance R from the axis for the measurement of gravitational attraction, since

$$(M + m)\, h' = Mh + mR$$

the new force at R is

$$F_R' = F_R\left(1 + \frac{mR}{Mh}\right)$$

When the end of the pendulum is similarly loaded for the determination of its radius of gyration, since

$$i'^2 = i^2 + mR^2/M$$

the new period is

$$T' = T \sqrt{\frac{1 + \frac{m}{M} \quad \frac{R^2}{i^2}}{1 + \frac{m}{M} \quad \frac{R}{h}}}$$

Since T' and T are observed and m, M, R, h given, i may be computed. The horizontal pendulum itself thus supplies the value of i.

4. *Observations with a grating rotating on a fixed vertical axis.*—When the opaque mirrors M and N are identically concave and are put on the ordinary interferometer at a distance equal to their radius of curvature from the stationary grating, the latter may be rotated (without translation) as far as the breadth of the opaque mirror N permits, without readjustment. The ellipses are not lost. Inasmuch, however, as different thicknesses of glass are introduced into the rays when the grating is rotated, the ellipses travel horizontally through the spectrum from the red to the violet end or the reverse. They are about equally clear in all positions. A displacement at the mirror N of about 4 centimeters per meter, *i. e.*, ·04 radian, is equivalent to 2·3° of reflected ray, or a rotation of 1·15° for the grating, were within the scope of the interferometer and the tests were made within this limit. It is far in excess of anything required in the horizontal pendulum. No doubt, if the mirror N had been wider, the ellipses could have been retained for larger angles of rotation of the grating, though they would in such a case travel several times through the spectrum. The micrometer at M would have to be used.

If long columns of glass are to be inserted in either beam (GM or GN) the concave mirror is not available, since the direct slit images will then have different focal positions. The rays issue from the plane parallel column, parallel to this focal direction, but from a virtual focus nearer the concave mirrors. Hence, if the column is placed in the beam GM, the beam GN will, as a rule, have to be correspondingly shortened. The algebraic relations are complicated.

5. *Observations with the interferometer.*—The horizontal pendulum with which the following observations were made had the following constants, M being the total mass of the fixed parts, m the attached mass, h the distance of the center of gravity from the axis, R the distance of the vertical line of light on the grating (also mean distance of m and of F_R) from the axis, ϕ the inclination of the axis, H the indicated length and L the vertical pendulum length. $M = 1250$ grams; $m = 227$ grams; $h = 80$ centimeters; $R = 111{\cdot}3$ centimeters.

The observed periods (primes refer to the loaded pendulum) for M and $M + m$ were

$$T = 18{\cdot}48 \text{ seconds} \qquad T' = 18{\cdot}87 \text{ seconds}$$

Thus $i = 85{\cdot}1$ cm.; $\phi = a/\theta = {\cdot}01081$ rad. $= {\cdot}62°$, and $H = 7394$ cm.; $L = 8488$ cm.; $H' = 7834$ cm.; $L' = 8853$ cm.

Since $\theta = \Delta N/2R$ when ΔN is the mean displacement for the horizontal deflection (θ) of the pendulum

$$a = 10^{-5} \times 4{\cdot}86\ \Delta N \text{ radians.}$$

Thus, if $\Delta N = 10^{-4}$ cm., $a = 10^{-3}$ seconds of arc, or the change of a per vanishing interference ring ($\Delta N = 10^{-6} \times 30$) is ·000310 seconds of arc. This limit could easily be decreased to 10^{-6} 30″ by increasing T a little over three times.

Similarly, the forces at distance R from the axis of the horizontal pendulum are

$$F' = F\left(1 + \frac{m}{M}\frac{\mathrm{R}}{h}\right)$$

$$F_R = 42{\cdot}9\ \Delta N;\quad F_R' = 53{\cdot}7\ \Delta N$$

Thus if $\Delta N = 10^{-4}$ cm., $F'_R = {\cdot}0054$ dynes or about ·0016 dynes per vanishing interference ring, in case of the pendulum loaded with the disc m. In case of the two discs used below, $m = 227$ grams, $m' = 1035$ grams, placed all but in contact, $d = {\cdot}5$ cm., the gravitational attraction should exceed

$$f = 6{\cdot}7 \times 10^{-8}\ \frac{1035 \times 227}{({\cdot}5)^2} = {\cdot}063 \text{ dyne}$$

or ΔN should exceed ·00117 cm. or 2·3 drum parts on the micrometer or over 5 drum parts (about 80 interference rings) for the difference of deflection on the two sides of the suspended disc. This should already have been measurable in spite of the pendulum used, which was heavy and ill designed for the purpose.

In fig. 4 an example of the observations has been inscribed, the ordinates being the inclination of the pier, a, in hundredths of a second of arc, very nearly. It will be seen that the inclination increases as a whole from the beginning to the end of the month, the total range lying within something over two seconds of arc. The rise is particularly marked and sustained after the 14th, and the difference of inclination between the first and second half of the month is about one second.

As the observations were made in an unavoidably steam-heated room it is probable that the flexure of the pier, etc., due to thermal causes has been largely operative in modifying the trend of the curve. For on comparing the curve as a whole with the thermostat sheets (not shown) a retarded effect is possibly suggested, such as one would suspect if variations of surface temperature should penetrate massive masonry. It would then be possible for the curve to have different heights at the same temperature. Naturally, such comparisons are very vague, and it is the range of values of admissible in the apparatus which is here of paramount interest. Furthermore, as the hill on which the laboratory stands is, at present, being

tunnelled, so that the building is subject once or twice a day to the tremors resulting from the vigorous blasting underground, adequate conditions for the installation of an apparatus of the present kind are still remote. It is really surprising that interferometer observations could be made, without essential difficulty, under these circumstances. During an

Fig. 4.

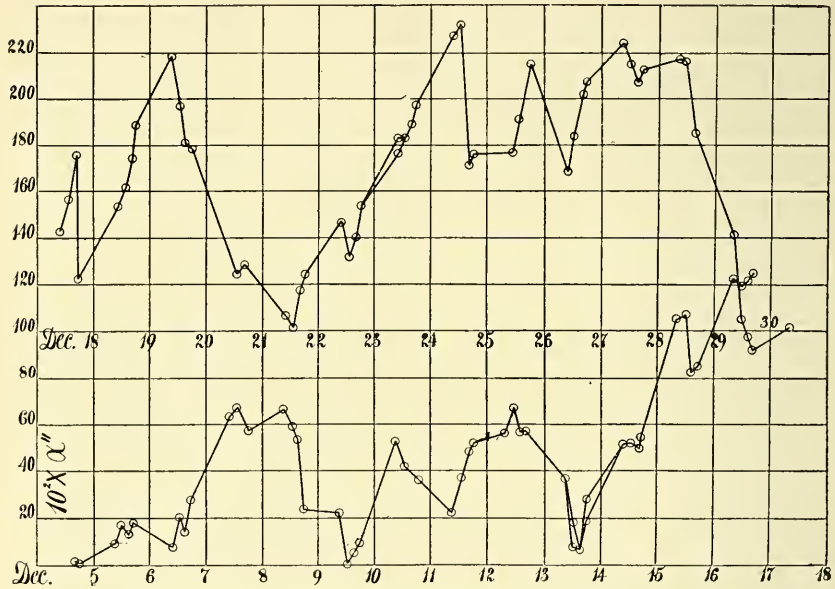


Fig. 4. Tilting of the pier in hundredths of a second of arc, showing the range of measurable a. The lower limit of a, 10^{-3} second, would not be visible in the diagram.

explosion, of course, the ellipses vanish; to reappear, however, immediately after, sometimes with displacement, such for instance as is indicated by certain of the doubled parts of the curve. The use of the water damper, moreover, which was necessary here, is objectionable, though it has not, probably, introduced any marked error into the observed curve (see also doubled parts). Finally, the use of a steel horizontal pendulum with its plane in the magnetic meridian is inadmissible. I have not, therefore, endeavored to interpret the results, but they are given simply as an example of a systematic series of observations, extending over a month. I hope in the summer to resume the work in the absence of the annoyances referred to.

I may add in conclusion that the experiments referred to above, for measuring the gravitational attraction of two identical brass discs, led to curious results. It is easily seen that for constant mass, the attraction of nearly contiguous discs should increase roughly as the fourth power of their radius. For discs 20^{cm} in diameter, however, the result is an invariable *repulsion*, several times as large as the estimated gravitational attraction, the position of equilibrium being reached gradually in the lapse of several minutes. Since the discs are identical and in metallic connection, it would seem as if the absolute electric voltaic contact potential of the metals is being measured. But this effect would be at least 100 times smaller than the observed value. Similarly, the gravitational pressure increment of the film of air between the discs is too small, so that the cause of systematic repulsion in the hundreds of experiments made is yet to be learned.

Brown University, Providence, R. I.

Art. XLII.—*On the Hydrolysis of Esters of Substituted Aliphatic Acids;* by W. A. Drushel.

[Contributions from the Kent Chemical Laboratory of Yale University—cclvii]

8. Homologues of Ethyl Cyanacetate.

From a study of the hydrolysis of ethyl cyanacetate* in dilute hydrochloric acid solution the reaction velocity was found to be lower than for the esters of the corresponding halogen substituted fatty acids. In view of this marked retarding effect in the ester hydrolysis apparently due to the presence of the cyanogen group, it seemed desirable to determine the rates of hydrolysis of other cyanogen substituted fatty acid esters in dilute acid solution. For this purpose the following esters were chosen:

Ethyl α-cyanpropionate $CH_3CH(CN)COOC_2H_5$,
ethyl β-cyanpropionate $CH_2(CN)CH_2COOC_2H_5$,
ethyl α-cyanbutyrate $CH_3CH_2CH(CN)COOC_2H_5$,
ethyl β-cyanbutyrate $CH_3CH(CN)CH_2COOC_2H_5$,
ethyl α-cyanvalerianate $CH_3CH_2CH_2CH(CN)COOC_2H_5$,
ethyl α-cyanisovalerianate $(CH_3)_2CHCH(CN)COOC_2H_5$, and
ethyl α-cyandiethylacetate $(C_2H_5)_2C(CN)COOC_2H_5$.

The ethyl esters of di-n-propylcyanacetic acid and di-isopropylcyanacetic acid were also prepared, but were found to be too insoluble in dilute acid to be of use in this work. For the purpose of comparison the ethyl esters of unsubstituted isovaleric acid, caproic acid and diethyl acetic acid were prepared and hydrolyzed.

Preparation of Esters.

(a) *α-Cyan substituted fatty acid esters.*—The previously named α-cyan esters were prepared by the method described by Henry,† and the monoalkylated esters were separated from the corresponding dialkylated esters by the method of Hessler.‡ A concentrated alcoholic solution of sodium ethylate was mixed with one equivalent of cyanacetic ester dissolved in an equal volume of absolute alcohol. Reaction took place immediately with the formation of the sodium salt of cyanacetic ester. Without separating the sodium salt it was treated in the flask with an excess of alkyl iodide added through a reflux condenser in small portions. The reaction was energetic and within 30 minutes the reaction mixture, consisting

* This Journal, xxxiii, 27.
† Henry, Jahresber, 1889, 637.
‡ Hessler, Amer. Chem. Journal, xxii, 169; ibid., xxxv, 990.

of the monoalkylated and dialkylated esters in alcoholic solution and separated sodium iodide with a small excess of alkyl iodide, became neutral to litmus. The mixture in each case was found to contain a large amount of the monoalkylated ester with a relatively small per cent of the dialkylated ester. The esters resulting from the introduction of the homologues of the methyl group were separated by the difference in the solubilities of the mono- and dialkylated esters in cold 10 per cent sodium hydroxide solution, the monoalkylated ester being readily soluble (with saponification) while the dialkylated ester is not appreciably attacked by cold dilute sodium hydroxide even when in contact with this reagent for several hours. After separation of the dialkylated ester the monoalkylated acid was recovered from the sodium salt and esterified.

(b) *β-Cyan substituted fatty acid esters.*—It was found possible to prepare ethyl beta cyanpropionate with an unsatisfactory yield from beta iodopropionic ester by a modification of Zelinsky's* method for the preparation of the corresponding alpha ester. One equivalent of finely powdered potassium cyanide was added to ethyl beta iodopropionate dissolved in absolute alcohol and heated at 100° in a sealed tube. A small yield of ethyl beta cyanpropionate entirely free from iodine and boiling at 110° under a pressure of 12^{mm} was obtained which was used in the hydrolysis experiments.

For the preparation of ethyl beta cyanbutyrate malonic ester was used as the starting out material. Malonic ester was first converted into ethylidene malonic ester by the method of Komnenos,† and from this ethyl beta cyanbutyrate was prepared by the method of Bredt and Kallen.‡ One mol of malonic ester was condensed with one mol of acetaldehyde in the presence of one and a half mols of acetic anhydride by heating in a sealed tube at 100° for two days. The condensation was made according to the following reaction, obtaining a somewhat less than fifty per cent yield: $CH_3CHO + CH_2(COOC_2H_5)_2 = CH_3CH : C(COOC_2H_5)_2 + H_2O$. The purified ethylidene malonic ester was heated at 60° for seven hours with one equivalent of potassium cyanide, a little water and a large excess of alcohol. The following reaction expresses this step:

$CH_3CH : C(COOC_2H_5)_2 + KCN + H_2O = CH_3CH(CN)CH_2COOC_2H_5 + HKCO_3 + C_2H_5OH$. The ethyl beta cyanbutyrate obtained in this way after purification boiled at 110°–112° under a pressure of 20^{mm}, and did not decolorize a dilute

* Zelinsky, Ber. Dtsch. Chem. Gesellsch. xxi, 3162.
† Komnenos, Liebig's Ann. Chem. Pharm., ccxviii, 157.
‡ Bredt, Kallen, ibid., ccxciii, 351.

bromine solution, showing it to be free from ethylidene malonic ester.

(c) *Unsubstituted fatty acid esters.*—The ethyl esters of propionic acid, butyric acid, isobutyric acid and isovaleric acid were obtained by esterifying these acids with absolute alcohol in the presence of a current of absolute alcohol vapor. Ethyl diethylacetate was prepared from acetoacetic ester by the successive introduction of two ethyl groups, saponification with concentrated alcoholic potassium hydroxide and esterification of the resulting disubstituted acetic acid as described above.

Hydrolysis of Esters.—The esters of this series were hydrolyzed in decinormal hydrochloric acid at 25°, 35° and 45° and the velocity constants were calculated from the titration formula for monomolecular reactions. On account of the small solubility of some of these esters it was necessary to use saturated solutions in order to give a sufficiently large range in the titrations to secure satisfactory velocity constants. The acid was warmed to the required temperature in the thermostat and was then shaken for a minute with an excess of the ester. The solution was filtered through a wet filter paper in order to obtain a homogeneous reaction mixture by removing the excess of undissolved ester. The filtered mixture was returned to a flask in the thermostat and the initial titration was made without delay. A 60^{cm^3} portion of the filtered reaction mixture was sealed up in a tube and placed in a water bath at 70° to 80° to be used after several days for making the end titrations in duplicate. From time to time 25^{cm^3} portions of the reaction mixture were withdrawn from the flask in the thermostat and titrated with N/20 or N/25 barium hydroxide, using phenolphthalein as an indicator. In order to permit all readings to be made upon the scale of a 50^{cm^3} standardized burette with such dilute alkali a bulb was sealed to the top of the burette (as described in a former paper§ from this laboratory) of such size as to allow the reading of the initial titration to fall within the first 10^{cm^3} of the burette scale. In this way it was possible to make titrations with a sharp end-point and a minimum error due to burette readings and at the same time a satisfactory range of titrations was obtained for calculating the velocity constants.

The time in minutes during which the course of each reaction was followed by titrations and the constants calculated from the velocity equation for monomolecular reactions are recorded in detail in Table I, and in summary form in Table II. In Table II are also recorded the temperature coefficients calculated for the intervals from 25° to 35° and from 35° to 45°, and the ratios of the velocity constants of cyan-substituted

* Dean, this Journal, xxxvii, 331.

esters for decinormal hydrochloric acid at 25° to the velocity constants of the corresponding unsubstituted esters.

From the results obtained it appears that the presence of the cyanogen group in the acid radical has in general a very marked retarding influence upon the velocity of the hydrolysis of the esters of such acids. In this respect cyanogen behaves like halogen, but the retarding effect of cyanogen, unlike that of the halogens, is more marked when the cyanogen has the alpha position than when it has the beta position. This influence of position was observed in both the cyanogen substituted propionates and the cyanogen substituted butyrates.

At the temperatures and acid concentration used in this series of experiments no hydrolysis of the cyanogen group was observed.

TABLE I.

Hydrolysis at 25° N/10 HCl

Ester	Ethyl cyan-propionate *a*	Ethyl cyan-propionate *β*	Ethyl cyan-butyrate *a*	Ethyl cyan-butyrate *β*	Ethyl *a*-cyan-valerianate	Ethyl *a*-cyan-isovalerianate	Ethyl *a*-cyan-diethylacetate
Time	14580	12000	14580		19200	19200	14580
10^5K	9·90	12·7	6·31		(6·88)*	2·64	2·68
	9·10	12·0	(5.47)*		4·90	(3·07)*	2·90
	9·17	12·8	6·25		4·53	2·58	2·59
	9·06	13·2	6·12		4·55	2·31	2·37
	9·16	13·4	6·32		4·68	2·25	2·69
	8·60	13·4	6·19		4·67	2·72	2·40
	8·90	13·6	6·38				
	9·23	13·3					
Average	9·14	13·0	6·15		4·67	2·50	2·58

Hydrolysis at 35°

Time	6060	6060	13200	6930	6930	6930	6930
10^5K	22·5	33·3	14·2	20·6	13·7	6·76	(7·40)*
	24·0	33·2	14·5	20·1	13·5	6·55	6·46
	22·9	33·5	13·9	20·4	13·4	6·32	7·08
	22·8	33·4	14·1	21·0	14·1	6·46	6·02
	22·5	33·8	13·9	20·4	14·1	6·30	6·17
	22·5	(28·7)*	13·9	20·2	13·5	6·54	6·52
	22·6	33·2	13·9	20·1	14·6	6·51	6·71
Average	22·7	33·4	14·1	20·4	13·9	6·49	6·53

* Not included in the average.

Hydrolysis at 45°

Time	3240	3240	3240	3240	3240	3240	3240
	47·5	77·0	34·2	46·6	31·2	17·6	14·5
	47·8	76·1	34·4	47·0	30·6	20·5	14·7
	45·9	75·4	35·0	48·3	30·6	19·1	14·0
	44·9	74·3	35·5	49·2	30·4	20·5	13·8
10^5K	43·9	72·9	35·7	48·2	31·3	16·6	14·4
	44·4	71·7	34·9	47·0	31·3	17·0	14·4
	44·2	73·6	34·8	47·9	31·6	17·0	14·8
	44·5		35·2		31·0	16·6	
Average	45·5	74·2	35·0	47·8	31·0	18·1	14·4

Table II.

N/10 HCl.

45°.

Esters of unsubstituted fatty acids.—10^5K.

Ethyl propionate	Ethyl butyrate	Ethyl isobutyrate	Ethyl isovalerianate	Ethyl diethylacetate
406	236	203	106	57·3

Esters of cyanogen-substituted fatty acids.—10^5K.

25°.

Ethyl cyanpropionate *a*	Ethyl cyanpropionate *β*	Ethyl cyanbutyrate *a*	Ethyl cyanbutyrate *β*		Ethyl *a*-cyan-valerianate	Ethyl *a*-cyan-isovalerianate	Ethyl *a*-cyan-diethylacetate
9·14	13·0	6·15	....		4·67	2·50	2·58
				35°			
22·7	33·4	14·1	20·4		13·9	6·49	6·53
				45°			
45·4	74·2	35·0	47·8		31·0	18·1	14·4
				Temperature coefficients.			
				25° to 35°			
2·48	2·57	2·29	....		2·97	2·59	2·53
				35° to 45°			
2·00	2·24	2·48	2·34		2·23	2·78	2·15
				Mean for 10°			
2·24	2·41	2·37	2·35		2·60	2·68	2·34

Ratio of velocity constants for N/10 HCl and 25°.

Ethyl cyan-acetate	:	Ethyl acetate	0·157
Ethyl *a*-cyan-propionate	:	Ethyl propionate	0·128
Ethyl *β*-cyan-propionate	:	Ethyl propionate	0·180
Ethyl *a*-cyan-butyrate	:	Ethyl butyrate	0·118
Ethyl *β*-cyan-butyrate	:	Ethyl butyrate	0·169

ART. XLIII. — *Thermochemistry and the Periodic Law. Heats of Combination Linear Functions of the Atomic Weights of Related Elements;* by W. G. MIXTER.

[Contributions from the Sheffield Chemical Laboratory of Yale University.]

DIFFERENT writers have alluded to a periodicity in the quantity of the heat of formation of compounds. Mendeléeff* gives Laurie's diagram for expressing the periodic variation in the heat of formation of chlorides and states (1) that "Thomsen . . . saw a correlation in the calorific equivalents of analogous elements, although he did not remark their periodic variation; (2) that the uniformity of many thermochemical deductions must gain considerably by the application of the periodic law, which evidently repeats itself in calorimetric data, and if these data frequently lead to true forecasts, this is due to the periodicity of the thermal, as well as of many other properties, as Laurie remarked; and (3) that the heat of formation of the oxides is also subject to a periodic dependence which differs from that of the heat of formation of the chlorides, in that the greatest quantity corresponds with the bivalent metals of the alkaline earths (magnesium, calcium, strontium and barium) and not with the univalent metals of the alkalies, as is the case with chlorine, bromine and iodine." There has been, however, no study of thermochemistry in the light of the periodic law. Such a study reveals more than Mendeléeff suggests and shows in many instances that the heat of formation is a linear function of the atomic weight. We shall see the application of this law to elements of a series in Mendeléeff's classification and to the members of a group of closely related elements, such as the halogens and the alkali-earth metals. Also that the variation from linear in other cases is quite uniform.

The thermochemistry of the different series will first be considered and then the thermochemistry of the groups. Table I is a convenient arrangement of the elements to use in referring to the periodic classification.

Thermochemistry of the Series.

The thermochemistry of oxygen and chlorine is more complete than that of any other element, that is to say, the heats of formation of more oxides and chlorides are known than of any other class of compounds, hydrocarbons excepted. Hence only oxides and chlorides are included in the diagram, fig. 1. It should be understood that the total heats of formation of the higher oxides and chlorides are not represented but only the

* Principles of Chemistry, II, 30.

TABLE I. *Distribution of the Elements in Groups and Series or the Periodic System (Mendeléeff).*

	Group I.	Group II.	Group III.	Group IV.	Group V.	Group VI.	Group VII.	Group VIII.
Series.	R_2O	RO	R_2O_3	RO_2	R_2O_5	RO_3	R_2O_7	RO_4 { Higher Oxygen Compounds.
1	1 H							
2	Li 7	Be 9	B 11	C 12	N 14	O 16	F 19	
3	23 Na	24 Mg	27 Al	28 Si	31 P	32 S	35·5 Cl	
4	K 39	Ca 40	Se 44	Ti 48	V 51	Cr 52	Mn 55	Fe 56 Co 59 Ni 59
5	63·6 Cu	65·4 Zn	70 Ga	72·5 Ge	75 As	79 Se	80 Br	
6	Rb 85·5	Sr 87·6	Y 89	Zr 91	Nb 94	Mo 96	——	Ru 102 Rh 103 Pd 107
7	108 Ag	112 Cd	115 In	119 Sn	120 Sb	127·5 Te	127 I	
8	Cs 133	Ba 137	La 139	Ce 140	Pr 141 Nd 144	——	——	— — —
9	——	——	——	——	——	——	——	
10	——	——	Yb 172	——	Ta 181·5	W 184	——	Os 191 Ir 193 Pt 195
11	197 Au	200·6 Hg	204 Tl	207 Pb	207 Bi	——	——	
12	——			Th 232	——	U 238·5	——	

In this table most of the rare elements are omitted, and approximate atomic weights are used.

FIG. 1.

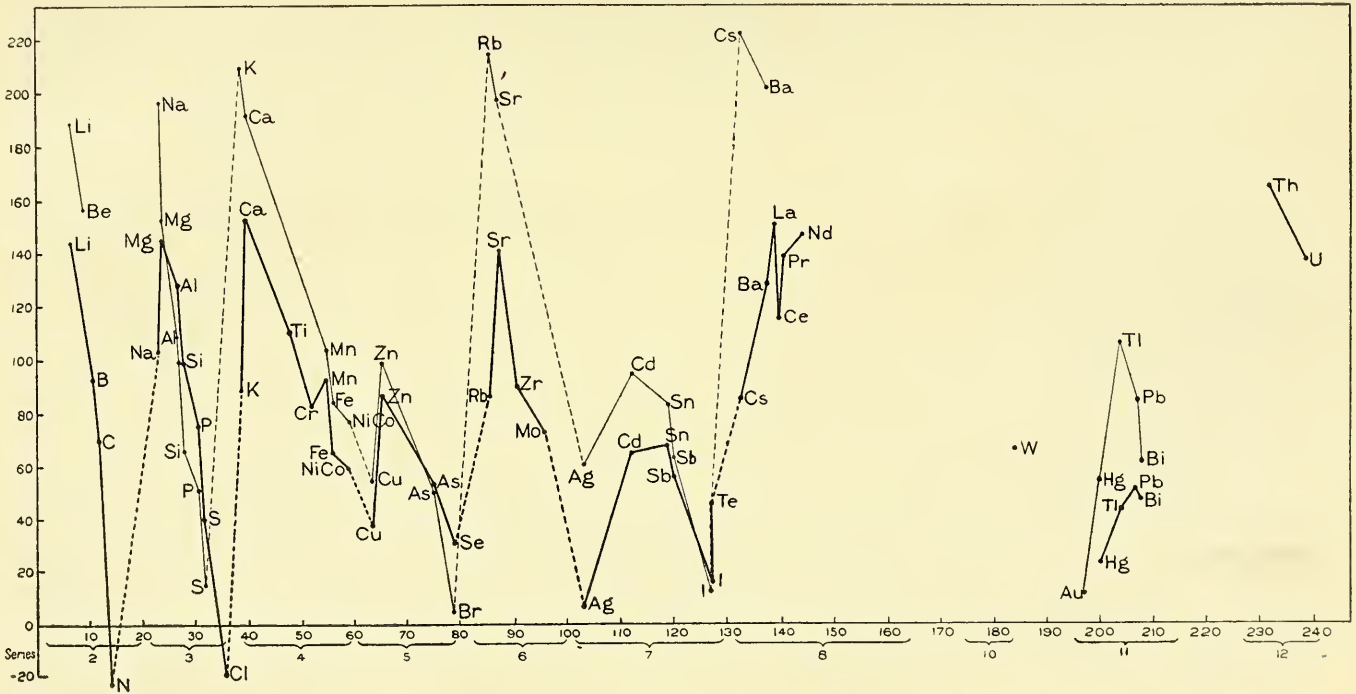


FIG. 1. Diagram of the heats of combination of 16 grams of oxygen and 71 grams of chlorine. The atomic weights are abscissas and the quantities of heat are ordinates. The oxides are on the heavy lines and the chlorides are on the light lines. The dotted lines connect one series with the next series.

heat effects of one gram-atom of oxygen and two gram-atoms of chlorine combining with the different elements.

Fig. 1 shows the periodic characteristics mentioned by Mendeléeff. It always shows that the quantities of heat fall in a series from the maximum with increasing atomic weights from the metals to the non-metals. The irregularities or variations from linear are due in part to the different molecular conditions of the elements combining, to the crystalline or amorphous form of the compounds resulting, and in part to the number of atoms of oxygen or chlorine in the compounds from which the values are obtained. Thus in series 2, Table I, we have lithium which probably has one atom in the molecule, and boron and carbon with doubtless complex molecules. The value taken for 16 grams of oxygen combining with boron is 1/3 the heat effect of 2B + 30. We do not know what B + O is In some cases, but not all, the heat effect of the first atom of oxygen is greater than the second. Hence there is some uncertainty attached to the values derived from the heats of formation of sesqui-, di- or trioxides.

The values in series 3 are the heats of formation of Na_2O, MgO, Cl_2O, 1/3 of Al_2O_3, 1/2 of SiO_2 and SO_2, and 1/5 of P_2O_5. The elements with even valence, magnesium, silicon and sulphur, fall nearly on a line as regards their heat equivalents, while aluminum, phosphorus and chlorine, having odd valences, fall on another line. Aluminum and phosphorus oxides have higher heats of formation than indicated by their atomic weights and position in the series. Potassium oxide falls on a line between chlorine of series 3 and calcium of series 4. The values of the oxides in series 4 are for Cr_2O_3 (1/3), FeO and MnO, and crystalline TiO_2(1/2), NiO and CoO. Omitting MnO, the curve is fairly regular from CaO to CuO. The heat equivalents of the chlorides of the series fall quite regularly. The values in series 5 are for amorphous CuO and ZnO, and crystalline As_2O_3(1/3) and SeO_2(1/2). In series 6 strontium chloride falls on the line between rubidium chloride and silver chloride of series 7. The values for one atom of oxygen combining with iodine, cæsium, barium and lanthanum are nearly linear. For tellurium it is high and the heat of formation of TeO_2 is greater than that of SeO_2. In series 11 the values are relatively low while in series 12 the quantity of heat evolved by 16 grams of oxygen uniting with thorium exceeds that of a combination of oxygen with any other element.

Thermal data to complete the diagram fig. 1 are lacking for a number of the rare elements and fluorine does not combine with oxygen or chlorine. In some of the series the quantities of heat appear to be nearly linear functions of the atomic weights. It should be observed, however, as the increase in

atomic weight from one element to the next is small, that any variation from linear in the diagram signifies a large difference from what the heat effect would be if it were a linear function. For example, if silicon were on the line connecting aluminum and phosphorus its heat of oxidation would be nearly as high as that of aluminum.

While it is not yet possible to account for the irregularities shown by the diagram, this may be stated. The rise or fall in the quantities of heat evolved by 16 grams of oxygen and 71 grams of chlorine is fairly regular in a series.

Thermochemistry of the Groups.

The heat equivalents of the members of a sub-group vary more regularly than they do in a series in the Periodic System. Some marked peculiarities in the thermochemistry of small groups have been observed. For example, Thomsen* states that in the groups, sulphur, selenium, tellurium, and phosphorus, arsenic, antimony, the heat of oxidation of the middle member exceeds that of the last. Also—"The affinity of water is greatest for baryta and least for lime";† and in each of the groups of non-metals the affinity of hydrogen is greatest for the first member and falls with an increase of atomic weight."‡ Thomsen§ discusses at length the "Dependence of the Thermal Effect upon the Molecular Weights of the Reacting Substances," and states, "There is at present no satisfactory answer to the question as to the relation between the thermal effect and atomic weight, although some such connection may be observed in the material under consideration." He apparently did not notice that in a group of three closely related elements the one with an atomic weight nearly the mean of the other two has a heat of combination nearly the mean of the others. For example, hydrogen bromide has a heat of formation the mean of that of hydrogen chloride and hydrogen iodide.

The data used in the discussion are, unless otherwise stated, from the Physikalisch-Chemische Tabellen, edition of 1912. The investigators quoted are indicated by initials or otherwise. They are Thomsen, Berthelot, Beketoff, Rengade, deForcrand and some others. The groups are taken up in order.

The most closely related elements in the first group are potassium, rubidium and cæsium. The fundamental values in the thermochemistry of these metals are derived from the quantities of heat evolved when they are dissolved in water. As the results of different investigators vary, the values in Table II are somewhat uncertain.

* Thermochemistry, 217.
† Ibid., 261.
‡ Ibid., 337.
§ Ibid., 360.

Table II.

	Potassium	Rubidium	Cæsium
R + Aq	46·4 R	47·2 R	48·5 Cal. R
	48·1 T	48·2 Bek.	51·0 Bek.
	45·2 Johannis		
2R + O	86·8 R	83·5 R	82·7 R
	97·1 Bek.	94·9 Bek.	100·0 Bek.
R + O + H	102·8 deF.	102·0 deF.	101·3 deF.
R + Cl	105·2 deF. & T	105·9 deF.	109·9 deF.
2R + S + 4O	343·9 deF. & T	344·7 deF.	349·8 deF.

Rengade appears to be the only one who has determined the heats of solution of all three of the metals, namely, potassium, rubidium and cæsium. Hence his results only are incorporated in Table III for these values. For a similar reason deForcrand's are taken for the chlorides and sulphates since we have only his experiments on the heats of formation of the rubidium and cæsium compounds. The values for KCl and K_2SO_4 are derived from K + O + H = 102·8 and Thomsen's data for HCl and H_2SO_4, the heats of neutralization and solution. As already suggested, there is some uncertainty in the thermochemistry of the alkali metals. It is best, however, to use the results of one investigator for analogous compounds as his errors are likely to be constant.

The numbers in brackets in Table III are linear values calculated from the atomic weights of the three metals and the heats of formation of the potassium and cæsium compounds.

Table III.

	Potassium	Rubidium	Linear values	Cæsium
2R + Aq	92·8	94·5	[94·8]	96·9 Cal.
2R + 2O + 2H	205·6	204·0	[204·1]	202·6
2R + O	86·8	83·5	[84·8]	82·7
2R + 2Cl	211·4	211·9	[215·6]	219·7
2R + S + 4O	343·9	344·7	[346·7]	349·8

The quantities of heat evolved when the three metals are dissolved in water are linear functions of their atomic weights. The same holds for the heats of formation of the hydroxides, while the observed result for rubidium chloride is 2 per cent below the linear value, and rubidium sulphate is 0·6 per cent low. The diagram fig. 2, where double atomic weights are made abscissas and heats of formation ordinates, shows the thermochemistry of the first group. The heat effects of the subgroup of potassium, rubidium and cæsium are linear, while those of the other members diminish irregularly with increasing atomic weights.

The fundamental values of the thermochemistry of the calcium, strontium and barium compounds are the heats of reaction of the metals with water or hydrochloric acid. For calcium we have Ca + 2HCl = 129·0 Cal. (Guntz & Bassett) and Ca + Aq = 94·1 Cal. (Moisson). These data give respectively Ca + O = 151·4 and 145·0 Cal. For strontium,

FIG. 2.

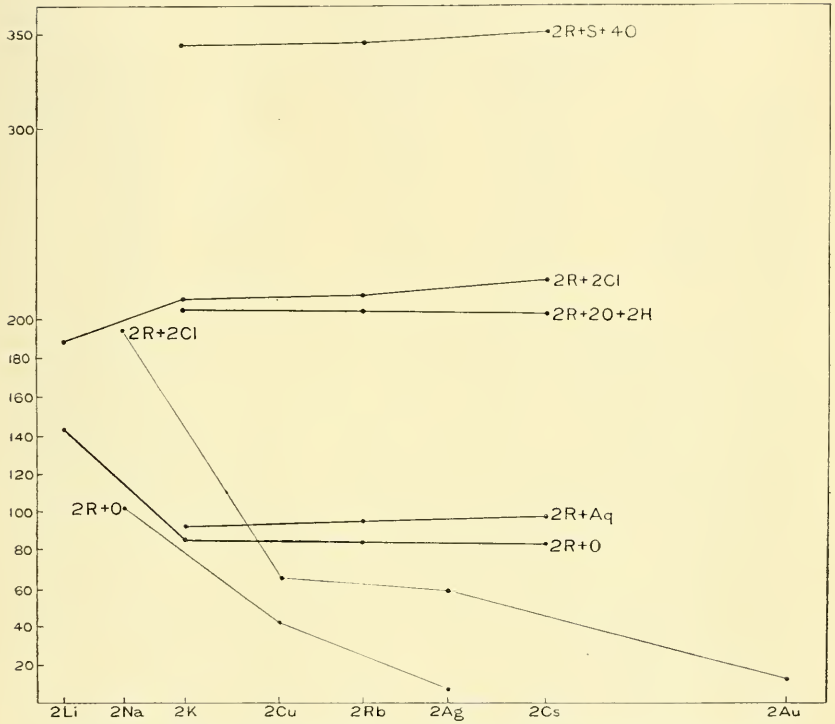


FIG. 2. Diagram of Group I. The heats of formation of the oxides and chlorides of lithium, potassium, rubidium and cæsium are connected by heavy lines, of the other elements of the group by light lines.

Sr + 2HCl = 117·05 (T) and 128·0 Cal. (Guntz & Roederer). Using Thomsen's values for the heat of solution of SrO, etc., we derive Sr + O = 128·4 (T) and 139·4 (G. & R.). For barium we have only Guntz's result, which is Ba + Aq = 92·5 Cal., which gives with Thomsen's values 126·4 Cal. for Ba + O. deForcrand by dissolving SrO,H_2O and BaO,H_2O in hydrochloric acid and combining his results with those of Guntz found that Sr + O = 138·6 Cal. and in more recent

work 137·6 Cal., and Ba + O = 125·6 Cal. Guntz is the only one who determined the heats of the reactions of all three metals and hence his values are used in this paper.

The values in Table IV are from Guntz's results and Thomsen's data for heat of neutralization and solution. Corrections are not made for the slightly lower atomic weights used by Thomsen than at present adopted. The linear values for the strontium compounds are derived as already described.

TABLE IV.

	Calcium	Strontium	Linear values	Barium
R + O	151·4	139·4	[139·2]	126·4 Cal.
RO + H_2O	15·5	17·7	[18·8]	22·3
R + 2H + 2O	235·3	225·5	[226·5]	217·1
R + 2Cl	190·4	195·4	[193·5]	196·8
R + S + 4O	338·8	342·2	[340·0]	341·2
RO + SO_3	84·2	99·6	[97·6]	111·6
R + C + 3O	291·0	291·8	[288·4]	285·6
RO + CO_2	42·6	55·4	[52·1]	62·2

The experimental values for the heat of formation of the strontium compounds in the table average 0·8 per cent higher than the calculated values with variations in some cases of about two per cent. The tabulated results make it appear probable that the heats of formation of these compounds are linear functions of the atomic weights. The thermochemistry of magnesium, zinc, cadmium and mercury shown in fig. 3 exhibits no such regularity and the quantities of heat fall irregularly with increasing atomic weights.

The thermochemistry of the third group includes only boron, aluminum, lanthanum and thallium and is not sufficient for use in the discussion.

The thermochemistry of the fourth group shown by fig. 4 presents certain abnormalities which will be considered later. The heats of formation of the dioxides of the elements in the even series are CO_2, 135;* TiO_2, 218·4; ZrO_2, 177·5; CeO_2, 224·6; ThO_2, 322 Cal. In the odd series they are SiO_2, 195†; SnO_2, 135·2; PbO_2, 62·4 Cal.

The characteristics of the thermochemistry of the fifth group are shown in fig. 5. The heats of formation, as Thomsen observed, of the antimony compounds are higher than the arsenic. Phosphorus combining with oxygen gives a larger quantity of heat than antimony, while with the halogens the

* C (vapor) + 2O = CO_2 + 135 Cal. (T).

†Von Wartenberg, Nernst Festschrift, 459, and Zentralblatt, 1912, II, 1095.

FIG. 3.

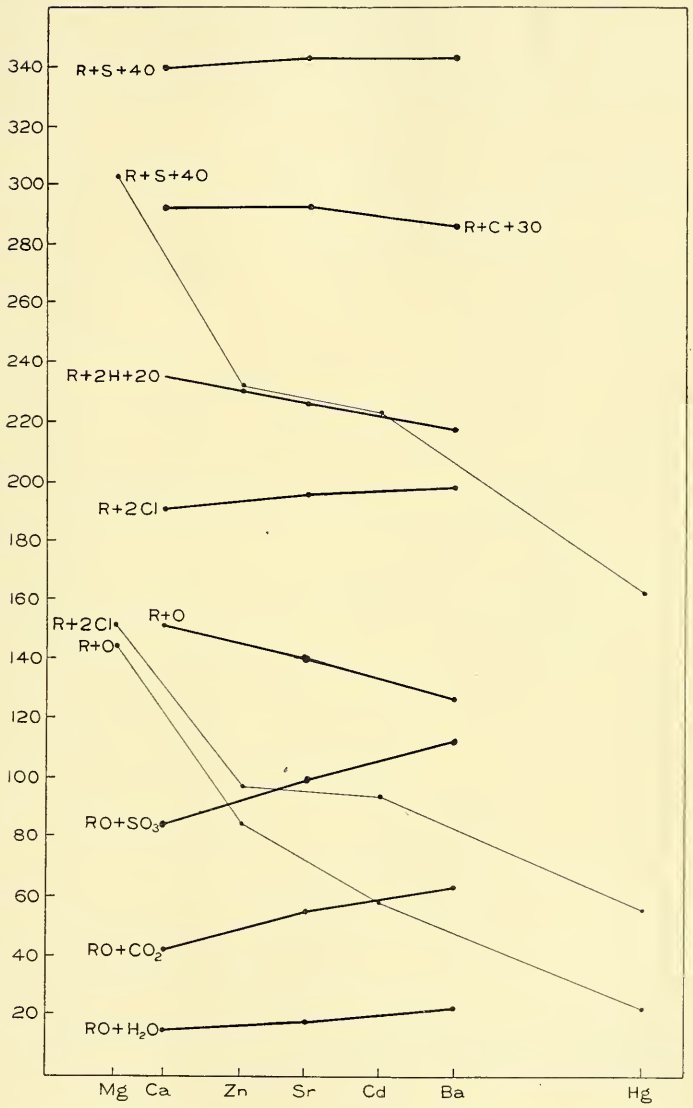


FIG. 3. Diagram of Group II. The heat equivalents of calcium, strontium, and barium are on the heavy lines, of the other elements of the groups on the light lines.

reverse holds. The only regularity found in the group is in the heat of combination of the pentoxides with sodium oxide. The values are $3Na_2O + P_2O_5 = 233$; $3Na_2O + As_2O_5 = 203$;

Fig. 4.

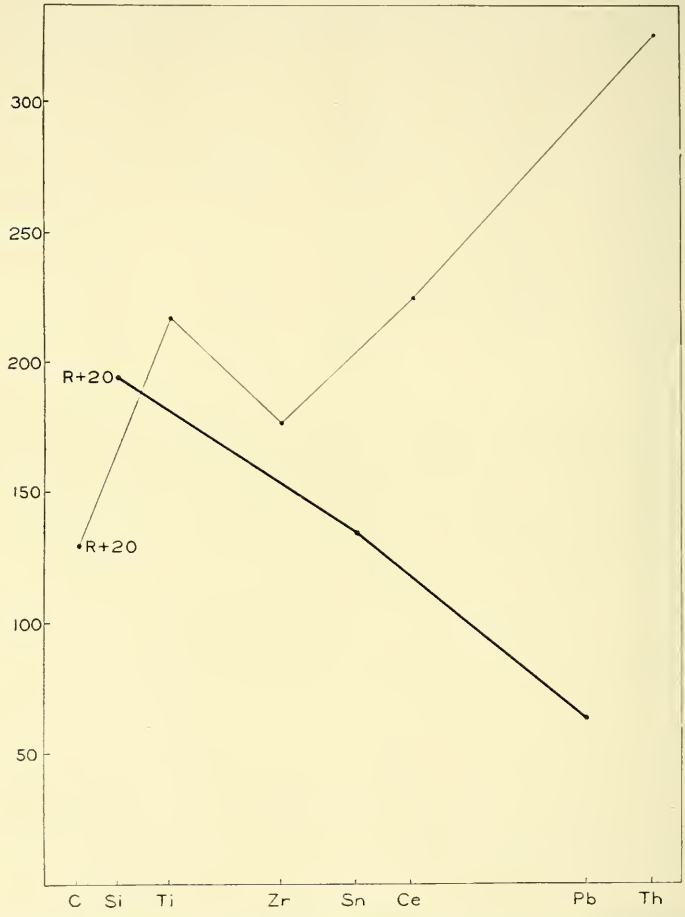


Fig. 4. Diagram of Group IV. The heats of formations of the dioxides of silicon, tin and lead are on the heavy line, of the other elements of the group on the light line.

$3Na_2O + Sb_2O_5 = 164$ Cal. The number 203 is 4 Cal. or 2 per cent higher than the linear value. The results given are the writer's and he considers that new determinations are required to show whether or not the heat effects of the above reactions

are linear functions of the atomic weights of phosphorus, arsenic and antimony.

The sixth group resembles the fifth in the irregularities of heat equivalents, and in both groups the only linear values are the heats of combination of the acidic oxides with sodium oxide. For the trioxides of the non-metals of the sixth group they are

$Na_2O + SO_3$	$Na_2O + SeO_3$	$Na_2O + TeO_2$
124·0	121·0 [124·0]	124·0 Cal.

Fig. 5.

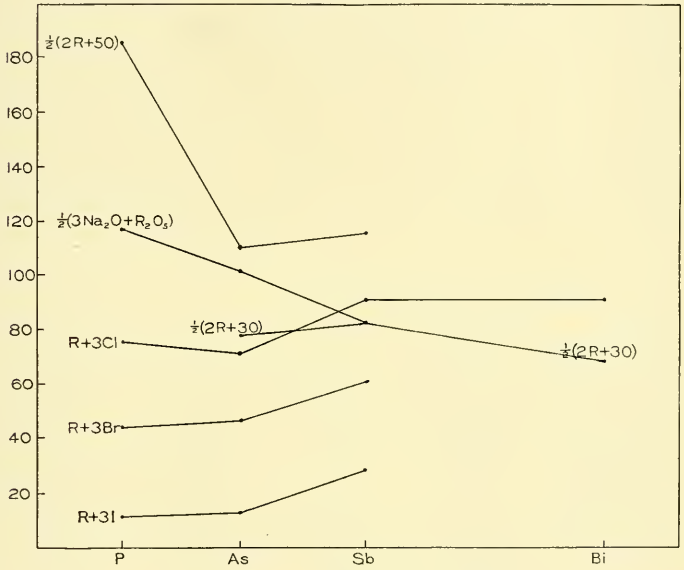


Fig. 5. Diagram of Group V.

The uncertainty in the value 121·0 Cal. is shown in the article on the above compounds.*

For the trioxides of the metals we have

$Na_2O + CrO_3$	$Na_2O + MoO_3$	$Na_2O + WO_3$	$Na_2O + UO_3$
77·0	81·9 [81·6] [82·9]	94·7 [90·50]	96·1 Cal. [101·7]

The calculated values are in brackets. Those in the first row are derived from 96·1 − 77 = 19·1 Cal., while 82·9 and 101·7 cal. are derived from 94·7 − 77 = 17·0 Cal.

* This Journal, xxix, 488, 1910.

Most of the heat equivalents of the sixth group were found by the writer,* and he would call attention to two of them, namely: $Na_2O + WO_3 = 94{\cdot}7$ Cal. and $Na_2O + UO_3 = 96{\cdot}1$ Cal. The first was derived by the heat of combustion of 98

Fig. 6.

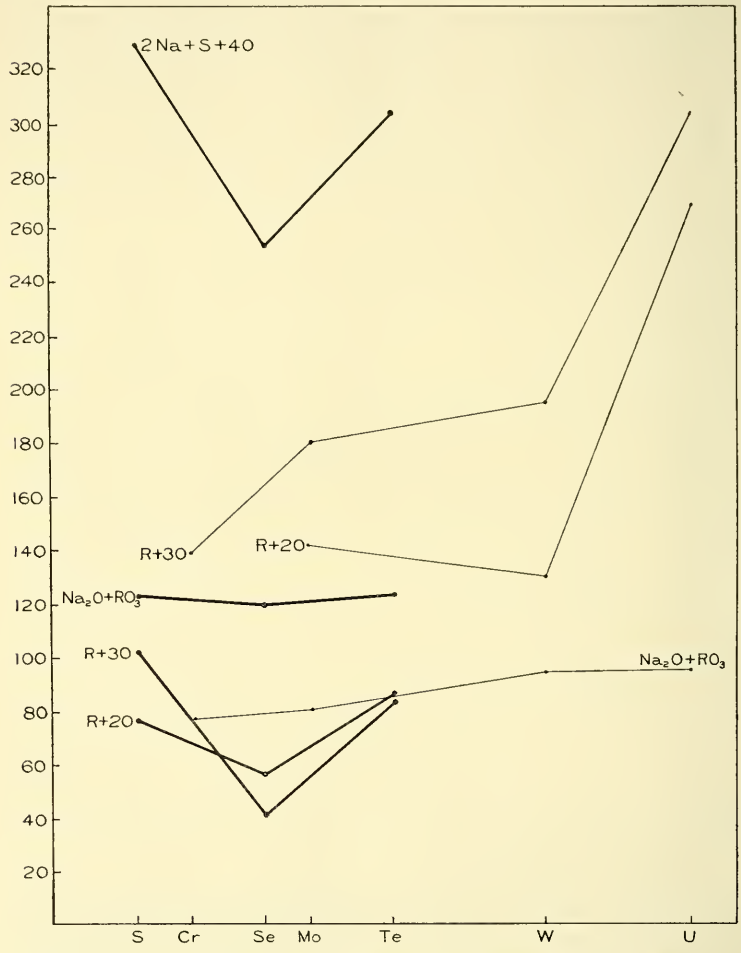


Fig. 6. Diagram of Group VI. The thermochemistry of sulphur, selenium and tellurium is shown by heavy lines, that of the other elements of the group by light lines.

*Chromium and tungsten, this Journal, xxvi, 125, 1908. Molybdenum, selenium and tellurium, ibid., xxix, 488, 1910. Uranium, ibid., xxxiv, 141, 1912, and Zeitschr. anorg. Chem., lxxviii, 22, 1912.

per cent tungsten with sodium peroxide and Delépine and Hallopeau's W + 30 = 196·3 Cal. The heat effect of 1 gram of uranium trioxide uniting with sodium was found to be 327, 342, 338 and 330°. With such small values the error may be large.

The thermochemistry of the halogens is commonly given for chlorine gas, liquid bromine and solid iodine. For comparison we must regard the three elements as in the gaseous state and take into account the heats of vaporization of liquid bromine and solid iodine. From data in Abegg's Handbuch, IV, 2. Abtheilung, p. 226, is derived 7·5 Cal. for the heat of vaporization of one gram molecule of liquid bromine at common temperature. Nernst* calculated the heat of formation of two molecules of hydrogen iodide from gaseous iodine to be 2·76 Cal., and Thomsen from solid iodine found it to be 12·07 Cal. The heat of vaporization of the one gram molecule of solid iodine at common temperature derived from these numbers is therefore 14·8 Cal.

Table V is made from Thomsen's data with the addition of 7·5 Cal. and 14·8 Cal. to the values of the bromine and iodine compounds respectively.

Table V.

	2Cl	2Br(gas)	Linear values	2I(gas)
2H	44·0	24·4	[24·0]	2·8 Cal.
2Na	195·4	178·9	[174·8]	153·0
2K	211·2	198·1	[193·6]	175·0
2Ag	58·8	52·9	[50·8]	42·4
Zn	97·2	83·4	[81·0]	64·0
Cd	93·2	82·7	[78·8]	63·6
Pb	82·8	72·0	[69·1]	54·6
2Cu	65·8	57·5	[56·8]	47·3
2Hg	65·2	58·5	[55·8]	45·9
Hg	54·5	49·4	[47·6]	41·4

Table V and fig. 7 show that the heats of formation of the bromides are a little higher than the mean of those of the chlorides and iodides. It would seem that this excess over the mean in all cases cannot be due to a constant error. Moreover, the results cited which are Thomsen's agree fairly well with those of Berthelot. When, however, we consider that, of the compounds given, only the heat of formation of hydrogen chloride has been found by direct synthesis and that all of the other values are derived indirectly, we may question whether the errors are not as great as the variations of the bromine

* Zeitschr. Electrochemie, 1909, p. 691.

compounds from the means of the heats of formation of the chlorine and iodine. The oxygen compounds of the group are not included in the diagram since no oxide of bromine is known. The bromates have a less heat of formation than the chlorates and iodates.

The elements in series 2 of the Periodic System stand apart from the other elements in thermochemical as well as in other properties. The same may be said of the elements with high

FIG. 7.

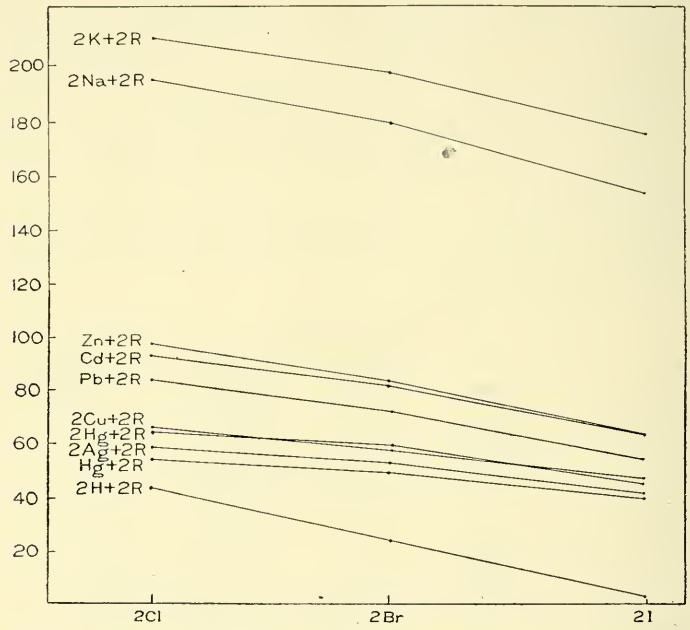


FIG. 7. Diagram of the heat equivalents of chlorides, bromides and iodides.

atomic weights in series 10, 11 and 12, though the differences between them and other elements is not so great as it is in the case of the elements of small atomic weights. Series 3 to 8 inclusive contains subgroups of elements having characteristics which vary with increasing atomic weights. The thermochemical data of the elements in these small groups are more complete than of the others and hence the study of the periodic dependence of heats of combination on atomic weights is limited with few exceptions to the series 3 to 8. The heat equivalents of the elements of some of the subgroups in both odd and even series are linear or nearly linear functions of the

atomic weights. This property appears in the following small groups in the even series:

Potassium, rubidium and cæsium of group I
Calcium, strontium and barium " " II
Chromium, molybdenum and tungsten in the combination of their acid anhydrides with sodium oxide, " " IV

In the odd series we have linear values for

Phosphorus, arsenic and antimony of group V
Sulphur, selenium and tellurium " " VI

in the combination of their acid anhydrides with sodium oxide.

Chlorine, bromine and iodine of group VII

combining with hydrogen and metals.

The six subgroups where the heats of combination vary with considerable regularity fall in five of the large groups of the Periodic System. New investigations are needed to determine whether the values are strictly linear or not. It is improbable, however, that any wide variation from linear will be found.

TABLE VI.

	$2Na+O$	$2Cu+O$	$Cu+O$	$2Ag+O$
	101	41	37 [54·6]	6 Cal.
Differences		13·6	17·6	
	$Mg+O$	$Zn+O$		$Cd+O$
	144	85 [103]		57 Cal.*
Difference		18		
	$Mg+S$	$Zn+S$		$Cd+S$
	79	41* [59]		24 Cal.*
Difference		18		
	$2P+5O$	$2As+5O$		$2Sb+5O$
	370	219 [300]		230 Cal.
Difference		81		
"	for 1 atom of oxygen	16		
	$S+3O$	$Se+3O$		$Te+3O$
	103	42 [93]		84
Difference		51		
"	for 1 atom of oxygen	17		
	$KCl+3O$	$KBr+3O$		$KI+3O$
	−9·8	−11·3 [16]		44 Cal.
Difference		27		
"	for 1 atom of oxygen	9		
	$MgO+SO_3$	$ZnO+SO_3$		$CdO+SO_3$
	55	42 [58]		62
Difference		16		

* This Journal, xxxvi, 55, and Zeitschr. anorgan. Chem., lxxxiii, 97, 1913.

The study of the irregularities in heat equivalents is limited with few exceptions to oxides, as complete data are lacking for other compounds. Considerations are limited as before to subgroups falling in series 3 to 8, where all of the subgroups, in which the heat equivalent of the middle member is considerably less than the linear value, are in the odd series 3, 5 and 7. The possible exception in case of zirconium, which is in the even series, will be noticed later. Table VI contains the heats of formation with calculated linear values in brackets and the differences between them and the experimental values.

In four subgroups in series 3, 5 and 7 the heat of oxidation of the middle member falls below the linear value the same amount for each atom of oxygen combined, or about 17 large calories. The same difference appears in the heats of the reactions Zn + S and ZnO + SO_3, but is less for KBr + 3O. Data needed to complete the study in series 3, 5, and 7 are lacking for gallium, indium and germanium and an element to follow molybdenum is wanting. The heats of oxidation of titanium, zirconium and cerium are irregular, as shown by the following:

Ti + 2O	Zr + 2O	Ce + 2O
218·4	177·5 [221·5]	224·6 Cal.

The heat of formation of ZrO_2 falls below the linear value 44 cal. or 22 Cal. for one atom of oxygen. This is a larger difference than found in other subgroups. Moreover, the three elements fall in the even series where the heat values are linear. Hence it appears probable that there are considerable errors in some of the values for the three dioxides.

The conclusion drawn from the study of the thermochemistry of the series 3 to 8 is this. The heat equivalents of the elements of a subgroup are either linear functions of the atomic weights, or the heat of formation of the oxide of the middle member falls below the linear value by a constant amount for each atom of oxygen combined.

It is desirable that new investigations be made of the small groups, as already suggested, and also determinations of the heat equivalents which are not known of the rare elements.

New Haven, Conn.

Art. XLIV.— *Picking Out and Mounting Diatoms;* by John M. Blake.

The art of selecting and picking out any considerable number of diatoms from a spread which contains a variety of species, and of arranging the selected diatoms successfully for mounting, appears to be attained by comparatively few persons. The methods by which successful results are secured are not generally known. Many workers are able to select a limited number of forms by the hand method of picking, but this method requires great concentration and nerve control. Among the difficulties to be surmounted, or at least allowed for, are the pulse beats that affect the hand, the high magnification making the pulsations quite apparent.

In 1895 the writer devised an apparatus which overcomes many of the difficulties. This apparatus is a small pantograph made of light wire. It reduces the motion of the hand twenty-six times. It consists of a jointed parallelogram (P) made of number 20 iron wire. This wire is flattened at the points where the rivets are placed. This parallelogram measures five inches on each side. Within this area, in one of its angles, is built a minute parallelogram twenty-six times smaller (s). This tiny parallelogram measures three-sixteenths of an inch on each side. The apex of the larger outer form (P) is coincident with that of the small inner member (s) and rotates on the same rivet. This rivet also passes through a short bit of wire and on this wire (P) can be rotated in its own plane. This rotation gives (P) a horizontal motion; while the short bit of wire itself rotates in bearings which give an up and down motion at right angles to the plane of (P), (P) itself slips over and around the body of the microscope.

The short bit of wire referred to has its bearings held about one quarter of an inch above the stage of the microscope. This leaves room for a glass slip one and one-half inches wide and six inches long to move underneath. A piece of sheet tin is bent so as to form a clip to spring over the farther edge of the microscope stage, and to this piece of tin the bearings of the short piece of wire are attached by supporting strips.

In use, the diagonally opposite apex of (P) is to be held in the hand and a short and finely pointed hair is attached by wax to the corresponding apex of (s). This hair is the implement for picking up the diatoms, and points in a downward direction. The diatom spread is made on a cover glass, and from this spread the selections are to be made.

This cover glass is attached by moisture to the first-mentioned slip of glass. The cover glass to which the diatoms are to be

transferred is also attached to this slip by wetting. The microscope is inclined, and the slip of glass rests on the stage and slides on the top edge of a thin strip of wood which also rests on the stage. This strip may be one-half inch in width and one foot long. Attached to this strip of wood from below are two broader strips which come level with the top of the stage, and form a shelf or a rabbet along which the slip of glass can slide. This narrow shelf forms a lateral extension to the stage of the microscope. Strips of wood attached by screws to the shelf from below bind it to the stage. These clamping pieces allow the shelf to be pushed up and down. The cover glasses mentioned can also be pushed up or down on the glass slip, provided we preserve the moisture under them. The pantograph can be adjusted in position by slipping the tin clip on the microscope stage.

(P) is so arranged and adjusted that the point of the hair comes into the field of the microscope. When it is desired to leave (P) for a time out of hand, a temporary support is provided so that the point of the hair is held just at the top of the field of view but raised a little so as to be partly out of focus.

When all the adjustments are completed the working of the apparatus is as follows: The glass slip is moved along on its shelf to bring the spread into view, and the hair point is employed to loosen any desired diatom. This selected diatom is then picked up by the hair. In very dry weather, electrical action often causes a good deal of trouble. Diatoms will sometimes suddenly jump out of the field. If we are successful in holding the diatom, it is then raised and the glass slip is moved to the position which brings the desired part of the reception cover into view, and the diatom is deposited at or near the desired place and worked about with the point until it is satisfactorily located. We now breathe upon the located diatoms through a flexible tube, which tube is attached in proper position for this purpose to the microscope objective. Gentle breathing causes adhesion to the prepared cover glass.

The preparation of the cover glasses is as follows: The covers are cleaned so that liquid will flow freely over them without creeping. They are then dipped, while held singly in clean forceps, in filtered gelatine solution containing ten grains of gelatine and five grains of sugar to the ounce. This is sometimes diluted to two volumes. The sugar may at times be omitted. We endeavor to adapt the gelatine solution to the atmospheric conditions at the time of coating. The gelatine itself may vary in quality. The aim is to make this coating sufficiently adhesive to hold the diatoms and at the same time not to have it run in and obscure them. Contact

with the fingers must be avoided. The covers are now stood on edge to drain and dry. Then a small central ring may be spun on them, and also a marginal ring to be mentioned later.

In this way any desired number of diatoms can be collected and located. It is well to have an intermediate stamping ground for temporarily depositing the selected diatoms where they can be cleared from adhering fragments before finally locating them. It is important to have all these cover glasses of the same thickness so that no time will be lost in focusing as we pass from one to the other.

One difficulty in picking up from a diatom spread will be found due to adhesion to the glass surface. This adhesion is caused by dissolved silica, or by some other soluble substance which may come from the glass surfaces, or from the water in which the diatoms are suspended. We may prevent this adhesion in part, by repeated settlings from freshly distilled water; but at the best, some of the more delicate shells will often break before they can be detached.

The writer has recently tried a plan which promises to be a help in such cases. This plan is to grind down thin slips of baked pipe clay or similar material. This material is then finely surfaced and ignited to drive off moisture. These slips may be blackened by charring sugar solution which can be soaked into them. They are then scrubbed in order to remove adhering particles, and again heated to drive off moisture. The diatom-spreading pipette is then drawn across the surface and the liquid is at once absorbed before it has time to dry on the surface and cause adhesion of the diatoms. Porous arc-light carbon may be ground down thin and used for this purpose. Reflected light must be used over these opaque surfaces. A two-thirds objective will give sufficient working space, and the eye-piece should be an erecting one.

Monobromide of naphthaline has usually been regarded as a difficult mountant to make secure. Several of the monobromide mounts made by the writer, however, in 1895 have kept in good order up to this date. For this reason it may be of interest to give some account of the method used in preparing them. They were sealed with gelatine. The refraction power of the unmixed monobromide used appears not to have suffered by lapse of time. Loss of refractive power has been reported to have occurred when a wax seal was employed.

The glass covers that have been coated with thin gelatine in the way that has been described are next given a marginal ring, and the reception slide itself is also given a preparatory ring. This treatment secures reliable contact of gelatine and glass, as both gelatine rings are dried before the monobromide is applied. A binding ring of warm gelatine

completes the adhesion of the two gelatine rings after the monobromide has been included. After this sealing ring has dried and has proved to be secure, and not till then, a final ring of shellac is applied. Any other cement that will resist the action of immersion fluids can be used in place of shellac. A recent sample of bleached lac has developed fine cracks on drying. The older slides did not show these cracks, in the rings. The use of shellac is to protect the gelatine from damp.

The gelatine preparatory rings were composed of gelatine twenty grains, sugar ten grains, and water two and one-half drams. These preliminary rings need not be thicker than the height the diatoms makes necessary. Experience has shown that these rings should be broad, and that the surfaces of contact should be perfectly even. The final sealing gelatine ring may be made of more concentrated gelatine, rendered as thick by evaporation of a portion of the original preparation as will flow easily from the brush. The flow will depend to a great extent upon the temperature of the room.

This gelatine seal can also be used for holding the solution of phosphorus in carbon disulphide when this solution is employed as a mounting medium.

Westville, Conn.

ART. XLV.—*The Chemical Composition of Bornite and its Relation to Other Sulpho-Minerals**; by E. H. KRAUS and J. P. GOLDSBERRY, with one text-figure.

Introduction.

IN September, 1912, the Mineralogical Laboratory of the University of Michigan purchased from the Ward's Natural Science Establishment of Rochester, N. Y., four specimens consisting of well-developed crystals or crystal aggregates of bornite from Bristol, Connecticut. The material was a part of an old collection which had recently come into the possession of this firm. As crystallized bornite is very rare, it was thought advisable to study this material first crystallographically, and then chemically, even though some of the crystals would have to be sacrificed, in order to determine whether or not some light might be thrown upon the question of the composition of this mineral.

Crystallography.

Crystals of bornite from Bristol, Connecticut, have already been studied, and according to Dana† the following forms and combinations noted: (100), (110); (111), (110), (100); and (111), (110), (211). On the four specimens at our disposal all of these forms, with the exception of the octahedron (111) were observed, and in addition the following were also noted: (221), (322), (433), (411), (522), (533), and (833). Of these (221), (433), (411), (522), and (833) are not listed by Goldschmidt‡ and, hence, are to be considered as new forms for bornite. As will be shown later all of these forms, with the possible exception of (411), are to be considered as well established.

Specimen 1.—This is a portion of an extremely well-developed crystal, but only the faces of one octant are present. The greatest length of the specimen measured about 2·5^{cm}. The observed forms are d (110), t (221), and i (211). Although the faces are not all of a uniform size d (110) predominates. One face of i (211) is the largest on the crystal, the other two being of intermediate sizes. Two of the faces of t (221) appear as small triangles, the third as a narrow plane between i and d. Fig. 1 shows the sizes and distribution of the various faces. All planes are striated, and the orientation of these striations,

* Read before the Geological Society of America at the Princeton meeting, January 1, 1914.

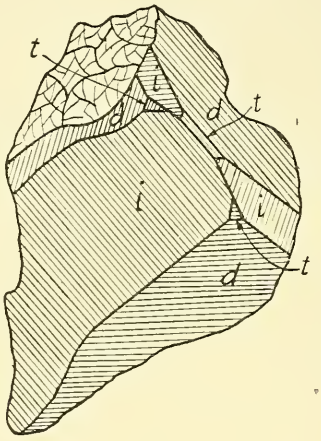
† System of Mineralogy, 5th edition, 45, 1868.

‡ Atlas der Krystallformen, 1913, I (text), 248.

as shown in fig. 1, indicates the symmetry of the hexoctahedral (holohedral) class of the cubic system. The lower portion of this crystal was subsequently sacrificed for the chemical analysis.

Specimen 2.—The following forms were noted: (100), (211), (322), (433), (522), and (533). The faces were not nearly as well developed as on specimen 1. Due to an oscillatory development of the various forms, tetragonal pyramids were built up on the faces of the cube, whereas trigonal pyramids

Fig. 1.



were formed on the corners of the same. The cube faces are the largest on the crystal, the others being usually quite small. The faces of the cube were dull and gave rather poor reflections. The signals obtained from the faces of the other forms were, however, sufficiently good to establish their identity. Some of the faces of the tetragonal trisoctahedrons were striated as shown in fig. 1.

Specimen 3.—This is a small crystal aggregate about 1·25^{cm} in length. The individual crystals showed the following forms: (100), (211), (322), (433), (522), and (533). Of the various forms, which were developed, those of the cube are the largest.

Specimen 4.—This was a crystal aggregate measuring several centimeters in length and made up of small, well developed cubes. The entire specimen was sacrificed for the chemical investigation.

In general there was a close agreement between the averages of the observed readings and the calculated values for the different angles, as is shown in the following table:

	Observed	Calculated
(110) : (101)	60°15′	60°
(110) : (112)	30 2	30
(110) : (221)	19 40	19 28′
(211) : (121)	33 43	33 34
(322) : (232)	19 41	19 45
(411) : (141)	60 28	60
(433) : (343)	13 45	15 56
(522) : (252)	43 15	43 21
(533) : (353)	25 4	24 55

Of the new forms for bornite (221), (433), (411), (522), and (833), only (411) should be considered as doubtful. The identification of this form is based upon only one measurement, the observed angle differing from the calculated by 28 minutes. The values for all the other angles, given in the table, are the averages of from two to eight readings.

*Earlier Interpretations of the Chemical Composition.**

For over one hundred years the chemical composition of bornite has been the subject of much discussion among mineralogists. Based upon the results of the earliest analyses of this mineral, Hisinger, Phillips, and Berzelius assumed bornite to be a mixture of the sulphides of copper and iron, as follows: $2Cu_2S + FeS$. Plattner in 1839 analyzed specimens of bornite from five different localities and concluded that the composition of crystallized bornite should be expressed by the formula $3Cu_2S + Fe_2S_3$. He, however, considered massive bornite as being variable in character, that is, a mixture of bornite of the above composition with chalcopyrite and chalcocite. In 1840 Schaffgotsch concluded that the composition of massive bornite could be best indicated by varying combinations of Fe_2S_3 and Cu_2S, thus one Fe_2S_3 with either 3, 5 or $9Cu_2S$. A little later, in 1841, Rammelsberg considered $Fe_2S_3.3Cu_2S$ as the correct formula, but assumed the admixture of varying amounts of Cu_2S in some varieties. In 1851 Forbes thought the composition of bornite should be represented by the following three mixtures: $CuS + 2Cu_2S$, $CuS + Cu_2S$, or $2CuS + Cu_2S$. Forbes, however, assumed that iron partially replaced copper.

By heating varying quantities of Cu_2O, CuO, and Fe_2O_3 in a current of H_2S at a temperature of about 200° C., Doelter,† in 1885, obtained small cubical crystals which he thought were bornite. The analyses, however, did not lead to any of the

* This summary is based largely upon Hintze's résumé, Handbuch der Mineralogie, I, p. 905, where references to the original contributions may be found.

† Zeitschr. Kryst., xi, 36, 1886.

then recognized formulas for bornite. Doelter, therefore, concluded that bornite could be considered as an isomorphous mixture of Cu_2S, CuS, and Fe_2S_3, in varying proportions.

Rammelsberg revised his earlier ideas in 1895 and gave as the general formula $p\ Cu_2S.q\ CuS.r\ FeS$, in which the relationship of the metals to the sulphur could vary greatly. Rammelsberg further considered the composition of crystallized bornite as $Cu_2S.CuS.FeS = Cu_3FeS_3$, but to some varieties he assigned the formula $Cu_{10}Fe_2S_8$.

Groth* in 1898 interpreted bornite as Cu_3FeS_3, and placed it in a group with chalcopyrite, $CuFeS_2$, and barnhardtite, $Cu_4Fe_2S_5$. These three minerals were thought to be derivatives of $Fe(SH)_3$. More recently Harrington,† in 1903, analyzed some crystallized bornite from Bristol, Connecticut, obtained from the Brush Collection of minerals of Yale University, and concluded from the results of the analysis of this and other material, and also from a study of previous analyses, that the chemical composition of bornite is best indicated by the formula $Cu_{10}Fe_2S_8$ or Cu_5FeS_4.

Chemical Investigations.

Inasmuch as crystallized bornite is exceptionally scarce it was thought advisable to use some of the material for an analysis, and accordingly all of specimen 4 and a portion of specimen 1 were sacrificed for this purpose. Specimen 4 consisted of an aggregate of cubical crystals. These were covered with a dark-colored coating which was thoroughly removed before the material was crushed for the analysis. The material from specimen 1 was the lower portion of the crystal represented by fig. 1, and was entirely free from any superficial coating. The material was, as far as could be determined by the ordinary methods, homogeneous in every respect. This was later substantiated by a careful metallographic study of specimen 1.

Sulphur was determined by oxidation to the sulphate with sodium peroxide and precipitation as $BaSO_4$. The copper was determined electrolytically, and the iron volumetrically by oxidation with potassium permanganate. The specific gravity of specimen 1 was determined as 5·086 at ordinary temperatures. The results of the analysis are as follows:

	I	II	Average	Ratios	
Copper	65·42%	65·91%	65·665%	1·03296	12·000
Iron	9·74	9·67	9·705	0·17377	2·019
Sulphur	24·79	24·51	24·650	0·76863	8·927
			100·020		

* Tabellarische Uebersicht der Mineralien, 4th edition, 29.
† This Journal, xvi, 151–154, 1903.

The above analysis leads to the formula $Cu_{12}Fe_2S_9$. This formula differs materially from the one, $Cu_{10}Fe_2S_8$, derived by Harrington from an analysis of crystallized bornite from this same locality, namely Bristol, Connecticut.

Inasmuch as we were confident that our material was well crystallized and homogeneous, and the methods of analysis could not be questioned, it was thought desirable to obtain and analyze some of the material used by Harrington for his analysis. Through the courtesy of Professor W. E. Ford a sufficient amount of bornite from specimen No. 805 of the Brush Collection of minerals of Yale University was placed at our disposal. This material was from the same specimen from which Harrington obtained his material. That the two analyses agree very closely is clearly shown by the following comparison:

	Harrington			Kraus and Goldsberry		
		Ratios			Ratios	
Copper	63·24%	0·9948	10·000	63·18%	0·9939	10·000
Iron	11·20	0·2005	2·016	11·38	0·2038	2·051
Sulphur	25·54	0·7964	8·005	25·43	0·7929	7·978
	99·98			99·99		

Since our analysis of this material agrees very closely with that made by Harrington and both lead to the formula $Cu_{10}Fe_2S_8$, we are confronted by the fact that here is a mineral, specimens of which from a single locality show a variable composition. It should be stated at this point that the material used by Harrington, and also by us in checking his analysis, was from a large specimen a portion of which is very well crystallized. Harrington had determined the specific gravity of this material to be 5·072. It will also be noted that this value is somewhat lower than that obtained by us on our material from Bristol, Connecticut, namely 5·086.

Metallographic Investigation.

In order to be certain that the material used for these analyses was homogeneous, surfaces were ground at random on our specimen No. 1 and on one of the larger fragments used for the check analysis of the Harrington material. This metallographic investigation was carried out on specimen No. 1 subsequent to the making of the analysis leading to $Cu_{12}Fe_2S_9$, but on the Harrington material before the analysis was begun. The surfaces were polished and examined under a metallographic microscope with magnifications of 85, 135, 200, and about 400 diameters without revealing the presence of any in-

clusions or admixtures. The surfaces showed absolute homogeneity, which was further confirmed by etching with nitrohydrochloric acid.

Interpretation of the Chemical Data.

It is now clearly evident that the material investigated consisted, in the cases referred to, of crystallized bornite, was homogeneous, possessed different specific gravities, and showed marked differences in chemical composition. That the analyses of crystallized bornite made by earlier investigators had also led to the formula $Cu_6Fe_2S_6$ must be emphasized here. We, thus, have three formulas which may be used to express the composition of the mineral we usually call bornite, namely $Cu_6Fe_2S_6$, $Cu_{10}Fe_2S_8$, and $Cu_{12}Fe_2S_9$. It is, therefore, necessary to determine how this great variation in composition can be explained most satisfactorily.

With this in mind the various analyses of bornite and chalcocite, as listed by Hintze,* were calculated for the possible formulas they might yield. The analyses of chalcocite were included in this study because it was found that one of them leads directly to the formula $Cu_6Fe_2S_6$, the one very commonly accepted for bornite. Another reason for including chalcocite is the fact that this mineral usually contains iron in varying amounts and, when massive, may resemble in many ways some bornites. Of the various analyses considered, it was found that thirty-eight lead quite directly to definite formulas. The following table shows the various formulas which resulted, arranged in order of increasing copper content. The number of analyses yielding these formulas is indicated in each case, and where possible the specific gravity is also given. It will be noted that by adding to the list the compound Fe_2S_3, not as yet found in nature, chalcopyrite, barnhardtite, and chalcocite, a most interesting series from Fe_2S_3 to Cu_2S can be arranged.

Name of mineral	Specific gravity	Formula	Number of analyses
		Fe_2S_3	
Chalcopyrite	4·2	$Cu_2Fe_2S_4$	
Barnhardtite	4·521	$Cu_4Fe_2S_5$	
Bornite	4·9	$Cu_6Fe_2S_6$	4
"	----	$Cu_8Fe_2S_7$†	3
"	5·072	$Cu_{10}Fe_2S_8$	17
"	5·086	$Cu_{12}Fe_2S_9$	4

* Loc. cit., pp. 914–916 and 537–538.

† This conforms to the formula generally accepted for tetrahedrite, see page 549. Some cupriferous tetrahedrites possess specific gravities slightly over 5 ; Dana, System of Mineralogy, 1892, 6th edition, pp. 139–140.

Bornite	5·248	$Cu_{14}Fe_2S_{10}$	5
"	----	$Cu_{16}Fe_2S_{11}$	2
"	----	$Cu_{18}Fe_2S_{12}$	1
:	:	:	
"	----	$Cu_{34}Fe_2S_{20}$	1
:	:	:	
"	----	$Cu_{40}Fe_2S_{23}$	1
:	:	:	
"	----	$Cu_{76}Fe_2S_{41}$	1
:	:	:	
Chalcocite	5·51	Cu_2S	

It appears then that there is here a regular progression in the chemical composition, by the addition of Cu_2S, from the end member Fe_2S_3, through to chalcocite, the other end member. The specific gravities, as far as determined, seem also to show a steady increase from the lower value to the highest, namely to that of chalcocite. Furthermore, the composition of any member of the series can be expressed by the general formula $Cu_xFe_2S_y$, where $y = \frac{x}{2} + 3$.

The criticism may be raised that the evidence for the existence of some of the compounds included in the above list is not sufficient, especially for those having large molecules. Further, that there is no positive evidence that the material used for analysis was always homogeneous, not having been examined metallographically. In reply to these criticisms, it may be stated that there are many sulpho-minerals the chemical compositions of which have not been questioned and which have not been studied metallographically. In fact, there are few minerals which have been investigated in this way. Also, there is no doubt in our minds but that the analysts in each case endeavored to get as homogeneous material as possible, and that $Cu_{18}Fe_2S_{12}$, for example, with but only one analysis at present as a basis, must, nevertheless, be considered as a definite compound, being analogous in composition to the well-established polybasite, $Ag_{18}Sb_2S_{12}$. The composition of many minerals is based upon more meager evidence than this, for example, that of prolectite. Although this mineral has never been analyzed, $Mg[Mg(F,OH)]_2SiO_4$ is assumed as its formula since its elements of crystallization are such as to place the mineral in the humite group.* This question of the composition of the various members of the above series will be discussed again.

There are few crystallographic data at present available with

*Groth, loc. cit., 119–120; Sjögren, Bull. G. Inst., Upsala, 1892, 1, 40, also 1894, 2, 99; Dana, loc. cit., 1st Appendix, 1899, 55; Doelter, Handbuch der Mineralchemie, 1913, II, 313–324.

respect to the various members of this series, but from what is known the crystallization of the various members may be interpreted as being either cubic or pseudo-cubic. The members, commonly called bornite, from $Cu_6Fe_2S_6$ to $Cu_{12}Fe_2S_9$ are known to belong to the cubic system. Chalcopyrite, $Cu_2Fe_2S_4$, is tetragonal, but pseudo-cubic, as is clearly indicated by its elements of crystallization: $a : c = 1 : 0{\cdot}9856$. Chalcocite, Cu_2S, is recognized as orthorhombic, $a : b : c = 0{\cdot}5822 : 1 : 0{\cdot}9702$, being the axial ratio given. If, however, the length of the a axis be doubled, and this does not cause serious difficulty with the resulting indices, we obtain $a : b : c = 1{\cdot}1644 : 0{\cdot}9702$, clearly indicating a pseudo-cubic character. Generally chalcocite is interpreted as pseudo-hexagonal on account of the value of the prism angle being 60°25′. It should, however, be pointed out that the rhombic dodecahedron of the cubic system also possesses angles of 60° and may accordingly be held so as to show an hexagonal development. In fact, beginners in crystallography often make this mistake when endeavoring to orient the rhombic dodecahedron. Furthermore, Groth* points out that Cu_2S may also be cubic. According to him the cubic modification is formed at high temperatures and on cooling passes over into the orthorhombic.

It, therefore, appears that from the crystallographic standpoint the relationships between the various members of this series are in accord with the conception of a regular progression in the chemical composition. In order to test this, the meager data concerning specific gravities and crystallization of the members of the series have been made use of in calculating the topical axes. In doing this barnhardtite has been assumed to be cubic. The specific gravity of chalcocite is that of some crystallized material from Cornwall, England, and was recently determined in this laboratory. The elements of crystallization used for chalcopyrite and chalcocite are those given above.

In determining the values of M, the molecular weight, and V, the equivalent volume, Fe_2S_3 and Cu_2S were interpreted as the end members of the series, and the various intermediate members as transition products. Hence, if the regular molecular weights be assigned to Fe_2S_3 and Cu_2S, those for chalcopyrite, barnhardtite, and so forth, are to be obtained by assuming the composition of chalcopyrite, $Cu_2Fe_2S_4$, to be $Cu_2S.Fe_2S_3$, that is the molecular weight of chalcopyrite may be placed equal to the sum of one-half of the molecular weights of each of the end members, namely 183·56. In a similar manner the weights of the other intermediate members of the series were obtained.

* Chemische Krystallographie, i, 135, 1906.

Name of Mineral	Composition	Molecular Weight, M	Specific Gravity	Equivalent Volume, V	χ	ψ	ω
----------	Fe_2S_3	207·91	----	-----	-----	-----	-----
Chalcopyrite	$Cu_2Fe_2S_4$	183·56	4·2	43·705	3·5407	3·5407	3·4897
Barnhardtite	$Cu_4Fe_2S_5$	175·44	4·521	38·806	3·3856	3·3856	3·3856
Bornite	$Cu_6Fe_2S_6$	171·39	4·9	34·977	3·2704	3·2704	3·2704
"	$Cu_8Fe_2S_7$	168·95	----	-----	-----	-----	-----
"	$Cu_{10}Fe_2S_8$	167·33	5·072	32·989	3·2072	3·2072	3·2072
"	$Cu_{12}Fe_2S_9$	166·17	5·086	32·672	3·1950	3·1950	3·1950
"	$Cu_{14}Fe_2S_{10}$	165·40	5·248	31·516	3·1587	3·1587	3·1587
"	$Cu_{16}Fe_2S_{11}$	164·62	----	-----	-----	-----	-----
"	$Cu_{18}Fe_2S_{12}$	164·08	----	-----	-----	-----	-----
	:	:					
Chalcocite	Cu_2S	159·21	5·51	28·895	3·4302	2·9466	2·8586

This table shows that the topical axes, which take into consideration not only the elements of crystallization, but also the chemical composition, as expressed by the molecular weights and the specific gravities, show striking similarities. Of the three axes, two, ψ and ω, vary quite regularly from their maximum values for $Cu_2Fe_2S_4$ to their minimum for Cu_2S. In the case of χ, there is a steady decrease down to $Cu_{14}Fe_2S_{10}$, the last intermediate member for which the axes can be calculated, and then an increase to Cu_2S. This change involves passing from the cubic to the orthorhombic system. These relationships are perhaps brought out a little more clearly in the following, where χ', ψ', and ω' are the values obtained when the topical axis, ψ, corresponding to the b axis of chalcocite, is taken as the unit for the whole series.

		χ'	ψ'	ω'
----------	Fe_2S_3	-----	-----	-----
Chalcopyrite	$Cu_2Fe_2S_4$	1·2016	1·2016	1·1843
Barnhardtite	$Cu_4Fe_2S_5$	1·1490	1·1490	1·1490
Bornite	$Cu_6Fe_2S_6$	1·1099	1·1099	1·1099
"	$Cu_8Fe_2S_7$	-----	-----	-----
"	$Cu_{10}Fe_2S_8$	1·0884	1·0884	1·0884
"	$Cu_{12}Fe_2S_9$	1·0843	1·0843	1·0843
"	$Cu_{14}Fe_2S_{10}$	1·0720	1·0720	1·0720
"	$Cu_{16}Fe_2S_{11}$	-----	-----	-----
"	$Cu_{18}Fe_2S_{12}$	-----	-----	-----
:	:			
Chalcocite	Cu_2S	1·1644	1·0000	0·9702

The topical axes show, therefore, progressive changes which, as far as can be determined from the very meager data concerning the specific gravities available at present, are fully in

accord with what should be expected from the progressive changes which have been assumed in the chemical composition.

Relation of the Minerals of the Fe_2S_3–Cu_2S Series to Other Sulpho-Minerals.

The general formula $Cu_xFe_2S_y$, given above, page 545, for the Fe_2S_3–Cu_2S series, may be further generalized so as to read $M'_xR'''_2S_y$, where again $y = \frac{x}{2} + 3$. Here M′ is principally copper, silver, or lead, more rarely zinc, tin, mercury, thallium, or bivalent iron, copper, cobalt or nickel. R‴ may be ferric iron, arsenic, antimony, bismuth, or trivalent chromium, nickel, or cobalt. Sulphur is sometimes partially replaced by selenium. With $M'_xR'''_2S_y$ as a basis, it is now possible to arrange a list of sulpho-minerals which show conclusively that the compositions given for the various members of the Fe_2S_3–Cu_2S series, page 544, correspond directly to those of well-established minerals. In this list the formulas are in nearly every case those recognized by Groth.*

General Formula $M'_xR'''_2S_y$, where $y = \frac{x}{2} + 3$.

Chalcopyrite	**$Cu_2Fe_2S_4$**
Lorandite	$Tl_2As_2S_4$
Miargyrite	$Ag_2Sb_2S_4$
Wolfsbergite	$Cu_2Sb_2S_4$
Emplectite	$Cu_2Bi_2S_4$
Scleroclase (Sartorite)	$PbAs_2S_4$
Zinckenite	$PbSb_2S_4$
Andorite	$(Pb,Ag_2)Sb_2S_4$
Galenobismutite	$PbBi_2S_4$
Alaskaite	$(Pb,Ag_2,Cu_2)Bi_2S_4$
Seleniferous Galenobismutite	$PbBi_2(S,Se)_4$
Daubreelite	$Fe''Cr_2S_4$
Linnæite	$(Ni,Co)''(Ni,Co)'''_2S_4$
Barracanite	$Cu''Fe_2S_4$
Carrollite	$Cu''Co_2S_4$
Barnhardtite	**$Cu_4Fe_2S_5$**
Dufrenoysite	$Pb_2As_2S_5$
Jamesonite	$Pb_2Sb_2S_5$
Kobellite	$Pb_2(Bi,Sb)_2S_5$
Cosalite	$Pb_2Bi_2S_5$

* Tabellarische Uebersicht der Mineralien, 4th edition, 1898, also the French translation with corrections and additions by Joukowsky and Pearce, 1904.

Schapbachite	$(Pb,Ag_2)_2Bi_2S_5$
Sychnodymite	$(Cu,Co,Ni)_2Co_2S_5$
Polydymite	$Ni_2Ni_2S_5$
Bornite	$\mathbf{Cu_6Fe_2S_6}$
Proustite	$Ag_6As_2S_6$
Pyrargyrite	$Ag_6Sb_2S_6$
Xanthoconite	$Ag_6As_2S_6$
Pyrostilpnite	$Ag_6Sb_2S_6$
Seligmannite	$Pb_2Cu_2As_2S_6$
Bournonite	$Pb_2Cu_2Sb_2S_6$
Aikinite	$Pb_2Cu_2Bi_2S_6$
Guitermanite	$Pb_3As_2S_6$
Lillianite	$Pb_3Bi_2S_6$
Bornite	$\mathbf{Cu_8Fe_2S_7}$
Tetrahedrite	$M'_5R'''_2S_7$*
M′ = Cu,Ag,Hg	
M″ = Fe,Zn	
R‴ = As,Sb	
Jordanite	$Pb_4As_2S_7$
Meneghinite	$Pb_4Sb_2S_7$
Bornite	$\mathbf{Cu_{10}Fe_2S_8}$
Stephanite	$Ag_{10}Sb_2S_8$
Geocronite	$Pb_5Sb_2S_8$
Bornite	$\mathbf{Cu_{12}Fe_2S_9}$
Kilbrickenite	$Pb_6Sb_2S_9$
Beegerite	$Pb_6Bi_2S_9$
Bornite	$\mathbf{Cu_{14}Fe_2S_{10}}$
Bornite	$\mathbf{Cu_{16}Fe_2S_{11}}$
Pearceite†	$(Ag,Cu)_{16}As_2S_{11}$
Polybasite†	$(Ag,Cu)_{16}Sb_2S_{11}$
Plumbostannite‡	$Pb_2(Fe,Zn)_2Sn_2Sb_2S_{11}$
Bornite	$\mathbf{Cu_{18}Fe_2S_{12}}$
Pearceite†	$(Ag,Cu)_{18}As_2S_{12}$
Polybasite†	$(Ag,Cu)_{18}Sb_2S_{12}$
Franckeite‡	$Pb_5Sn_2Sb_2S_{12}$
Polyargyrite	$Ag_{24}Sb_2S_{15}$
Bornite	$\mathbf{Cu_{34}Fe_2S_{20}}$
Cylindrite‡	$Pb_6Sn_6Sb_2S_{21}$
Bornite	$\mathbf{Cu_{40}Fe_2S_{23}}$

* This older, simpler, and generally accepted formula is retained for the present classification, even though Kretschmer has recently (Zeitschr. Kryst., xlviii, 484-513, 1910) suggested a more complex one, namely $xM'_9R'''_3S_9 + M''_6R'''_2S_9$. If $M'_9R'''_3S_9$ be written in its simpler form, $M'_6R'''_2S_6$, it will be noted that both of these components correspond to well-known minerals in the above list.

† Penfield (this Journal, xliv, 17, 1892) gave $Ag_{18}R'''_2S_{12}$ as the general formula for these minerals. Van Horn and Cook have, however, recently suggested $Ag_{16}R'''_2S_{11}$ (ibid., xxxi, 518, 1911, and xxxii, 40). Unquestionably both formulas hold good, the conditions being analogous to what is now shown to be the case for bornite with its varying composition, belonging as it does to the Fe_2S_3–Cu_2S series. Pearceite and polybasite are accordingly to be interpreted as being members of two similar series, namely, As_2S_3–Ag_2S and Sb_2S_3–Ag_2S.

‡ In these minerals tin is considered as being basic in character.

It is thus seen that many of the rarer minerals with complex molecules fall into this series. The chemical composition of some of these has generally, heretofore, been considered rather doubtful. Thus, to cite but one example, polyargyrite, $Ag_{24}Sb_2S_{15}$, has always been placed in a class by itself, but it now appears that its composition is such as to conform to the general formula of this series.

Other Series of Sulpho-Minerals.

(1) The klaprotholite group shows the general formula $M'_xR'''_4S_y$ where $y = \frac{x}{2} + 6$. These minerals are:

Klaprotholite	$Cu_6Bi_4S_9$
Rathite	$Pb_3As_4S_9$
(Binnite)	
Warrenite	$Pb_3Sb_4S_9$
Schirmerite	$(Ag_2,Pb)_3Bi_4S_9$
Boulangerite	$Pb_5Sb_4S_{11}$
Diaphorite	$(Pb,Ag_2)_5Sb_4S_{11}$
Freieslebenite	$(Pb,Ag_2)_5Sb_4S_{11}$

(2) Baumhauerite, $Pb_4As_6S_{12}$, has a composition which may be expressed by the general formula $M'_xR'''_6S_y$, where $y = \frac{x}{2} + 9$. This is the only mineral of this type thus far noted.

(3) The composition of plagionite, $Pb_5Sb_8S_{17}$, may be written to conform to the formula $M'_xR'''_8S_y$, where $y = \frac{x}{2} + 12$. Plagionite is the only member of this series thus far observed.

(4) The series of sulpho-stannates possesses the general formula $M'_xR'^{v}_2S_y$, where $y = \frac{x}{2} + 4$. M' may be silver, univalent copper, or bivalent iron; R'^{v} is either tin or germanium. The minerals of this series are:

Stannite	$Cu_4Fe_2Sn_2S_8$
Canfieldite	$Ag_{16}(Sn,Ge)_2S_{12}$
Argyrodite	$Ag_{16}Ge_2S_{12}$

(5) The series of minerals in which arsenic, antimony, vanadium are interpreted as having valencies of five conform to the formula $M'_xR^{v}_2S_y$, where $y = \frac{x}{2} + 5$. The series is as follows:

Enargite	$Cu_6As_2S_8$
Luzonite	$Cu_6As_2S_8$
Famatinite	$Cu_6Sb_2S_8$
Sulvanite	$Cu_6V_2S_8$
Epigenite	$Cu''_4Fe''_3As_2S_{12}$

It is thus evident that all the important sulpho-minerals listed by Groth, with the exception of the sternbergite series, can be made to conform to some one of the above simple general formulas. In the case of the sternbergite minerals it is very doubtful whether these are to be considered as independent species. We are strongly of the opinion that Groth is right when he intimates that sternbergite, argyropyrite, frieseite, and argentopyrite are probably only argentiferous pyrites.

The compositions of the various sulpho-minerals may therefore be referred to the following six general formulas:

$$M'_xR'''_2S_y, \text{ where } y = \frac{x}{2} + 3. \quad (1)$$

$$M'_xR'''_4S_y, \text{ where } y = \frac{x}{2} + 6. \quad (2)$$

$$M'_xR'''_6S_y, \text{ where } y = \frac{x}{2} + 9. \quad (3)$$

$$M'_xR'''_8S_y, \text{ where } y = \frac{x}{2} + 12. \quad (4)$$

$$M'_xR'^{v}_2S_y, \text{ where } y = \frac{x}{2} + 4. \quad (5)$$

$$M'_xR^{v}_2S_y, \text{ where } y = \frac{x}{2} + 5. \quad (6)$$

Some Morphotropic-genetic Series.

As a result of the foregoing considerations, it is now desirable to arrange and study the various progressive chemical series into which the sulpho-minerals may be classified. Several of the more important series of minerals with the general formula $M'_xR'''_2S_y$, where $y = \frac{x}{2} + 3$, are the following:

As_2S_3–PbS Series

		Specific gravity
Orpiment	As_2S_3	3·5
Sartorite	$PbAs_2S_4$	5·39
Dufrenoysite	$Pb_2As_2S_5$	5·56
Guitermanite	$Pb_3As_2S_6$	5·94
Jordanite	$Pb_4As_2S_7$	6·393
:	:	
Galena	PbS	7·45

Sb_2S_3–PbS Series

		Specific gravity
Stibnite	Sb_2S_3	5·32
Zinckenite	$PbSb_2S_4$	5·4
Jamesonite	$Pb_2Sb_2S_5$	5·57
:	:	
Meneghinite	$Pb_4Sb_2S_7$	6·399
Geocronite	$Pb_5Sb_2S_8$	6·3—6·45
Kilbrickenite	$Pb_6Sb_2S_9$	6·4
:	:	
Galena	PbS	7·45

Sb_2S_3–Ag_2S Series

		Specific gravity
Stibnite	Sb_2S_3	5·32
Miargyrite	$Ag_2Sb_2S_4$	5·18—5·3
:	:	
Pyrargyrite	$Ag_6Sb_2S_6$	5·85
:	:	
Stephanite	$Ag_{10}Sb_2S_8$	6·25
:	:	
Polybasite	$Ag_{16}Sb_2S_{11}$	6·067
Polybasite	$Ag_{18}Sb_2S_{12}$	6·33
:	:	
Polyargyrite	$Ag_{24}Sb_2S_{15}$	6·974
:	:	
Argentite	Ag_2S	7·3

Bi_2S_3–PbS Series

		Specific gravity
Bismuthinite	Bi_2S_3	6·5
Galenobismutite	$PbBi_2S_4$	6·88—7·14
Cosalite	$Pb_2Bi_2S_5$	6·39—6·75
Lillianite	$Pb_3Bi_2S_6$	6·7
:	:	
Beegerite	$Pb_6Bi_2S_9$	7·273
:	:	
Galena	PbS	7·45

Bi_2S_3–Cu_2S Series

		Specific gravity
Bismuthinite	Bi_2S_3	6·4—6·8
Emplectite	$Cu_2Bi_2S_4$	6·3—6·5
:	:	
Chalcocite	Cu_2S	5·51

A preliminary survey of several of these series shows that some very interesting relationships can be pointed out, for with but few exceptions the crystallization of the various members

can be interpreted as cubic or pseudo-cubic. Heretofore these minerals have been treated chiefly from the standpoint of isomorphism, but unquestionably a new study of the crystallography of the above groups will show that they are to be considered as morphotropic series, as has been shown for the Fe_2S_3–Cu_2S series. These relationships will be reported upon in detail later.

The arrangement of minerals into series of the above character is, we believe, fully justified not only by what was shown to hold good for the Fe_2S_3–Cu_2S series, but also by the characteristic methods of occurrence and association of the members of these series. This classification* of the sulpho-minerals will undoubtedly be of some service to economic geologists in studying the origin and formation of some ore deposits, for it is reasonable to assume that the members of each series were formed in many instances by the interaction of solutions of the various members, especially of the end members, or by solutions upon the solid phases of some of them.

Mineralogical Laboratory,
University of Michigan,
February, 25, 1914.

* Somewhat similar classifications are to be found in Tschermak's Mineralogie, 6th edition, 1905, 416–422; see also Spencer, Economic Geology, viii, 638, 1913, and Clarke's Data of Geochemistry, Bulletin 491, U. S. G. S., 2d Edition, 1911, 623, 628, 630, and 652.

SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *The Relative Abundance of Several Metallic Elements.*— F. W. Clarke and George Steiger have published the results of analyses of composite samples of several materials in order to show the amounts of some of the minor constituents occurring in the earth's crust. A great many different samples of each kind of material were mixed and the small constituents were determined in large portions of the combined samples. Interesting data were thus obtained in regard to the percentages of several familiar metals:

A. "Red clay" of oceanic depths, 51 samples.
B. Blue and green "terrigenous clays" from oceanic deposits, 52 samples.
C. Mississippi silt, 235 samples.
D. American igneous rocks, 329 samples.

	A.	B.	C.	D.	Average.
NiO	0·0320	0·0630	0·0170	0·0066	0·0296
As_2O_5	0·0010	trace	0·0004	0·0007	0·0005
PbO	0·0073	0·0004	0·0002	0·0008	0·0022
CuO	0·0200	0·0160	0·0043	0·0117	0·0130
ZnO	0·0052	0·0070	0·0010	0·0064	0·0049

The following percentages of other minor constituents were found in the composite samples of the earthy materials, while the last column shows the mean of many determinations in rocks :

	A.	B.	C.	Rocks.
BaO	0·17	0·05	0·08	0·086
SrO	0·046	0·025	trace	0·031
Cr_2O_3	0·01	0·044	0·01	0·031
V_2O_3	0·028	0·028	0·02	0·014
ZrO_2	undet.	undet.	0·05	0·015
Li_2O	----	----	----	0·008

The authors say that the data so far obtained may not be final, but they clearly indicate the several orders of magnitude which it was sought to determine.—*Chem. News*, cix, 159. H. L. W.

2. *The Spitting of Silver.*—H. B. Baker, considering the fact that the amount of oxygen absorbed by melted silver is so large that it seems difficult to explain it as a case of simple solution, has made an attempt to detect the presence of an oxide of silver in the molten metal, and has found that when very pure molten silver is partly covered with molten boron trioxide in an atmosphere of oxygen, a large amount of borate of silver is formed and dissolved by the boron trioxide, while if the surface of the silver is completely covered by the trioxide no silver borate is produced. These experiments appear to indicate the existence of silver oxide in the molten metal, although it cannot be claimed that an absolute proof has been obtained, because there is a possibility of the reaction of three substances together, no two of which will otherwise unite.—*Chem. News*, cix, 127. H. L. W.

3. *A Laboratory Guide to the Study of Qualitative Analysis*, by E. H. S. Bailey and H. P. Cady. 8vo, pp. 280. Philadelphia, 1914 (P. Blakiston's Son & Co. Price, $1.25 net).—The appearance of this seventh edition of this work indicates that it is extensively used. It has been changed but slightly from the previous issue. The book contains less printed matter than is indicated by its pages, as nearly half of them are left blank for notes. The book evidently gives a good course of analysis, but it has received adverse criticism on account of extensive use of the ionic nomenclature. This criticism appears to be warranted, in spite of the general acceptance and the undoubted importance of the ionic hypothesis in explaining why acids, bases, and salts readily exchange their radicals in solution.

The ionic equations are less satisfactory than molecular equations in showing the products of reactions, especially when the quantities of the reacting substances are under consideration. The extreme ionic view leaves out of consideration the large proportions of un-ionized compounds that occur in ordinary solutions, as well as the absence of ions in solids. The book carries out the ionic idea to an extreme extent. For instance, it says in connection with the removal of certain metals ("cations higher than group I") by boiling the solution with sodium carbonate, "If ammonium ions are present, the boiling should be continued until they are expelled." Now, since it is ammonia and not the ammonium ion that is expelled, it would appear better to mention it as such. The continual use of the word "ion" in the book seems to be unnecessary and unsatisfactory. It would seem simpler and better to speak of testing for phosphates instead of "the phosphate ion," for chlorides instead of "the chloride ion," for potassium instead of "the potassium ion," and so on, for it is not only superfluous, but it is inconsistent to refer to the examination of solids for ions.

H. L. W.

4. *Chemistry in America;* by EDGAR F. SMITH. 8vo, pp. 356. New York, 1914 (D. Appleton and Company).—Dr. Smith has rendered an important service to chemists by the publication of these "Chapters from the History of the Science in the United States." The book deals extensively with the early history of chemistry in Philadelphia, its important starting-point. There is much of interest regarding Joseph Priestly after his arrival in America; concerning Joseph Hare, the inventor of the compound blowpipe, and a celebrated investigator in other lines; in connection with the studies of the elder Benjamin Silliman at that city; and about many other interesting chemists. The book contains excellent portraits of Robert Hare, James Woodhouse, Joseph Priestly, Thomas Cooper, John Maclean, Samuel Latham Mitchell, Benjamin Silliman, James C. Booth, T. Sterry Hunt, J. Lawrence Smith, Wolcott Gibbs, M. Carey Lea, Josiah Parsons Cooke and J. Willard Gibbs. This list of portraits shows the scope of the book, although the work of many others is mentioned, usually briefly. No attempt has been made to discuss the chemical work of recent years. H. L. W.

5. *Annual Reports of the Progress of Chemistry for 1913.* Volume X. Issued by the CHEMICAL SOCIETY. 8vo, pp. 300. London, 1914 (Gurney & Jackson, 33, Paternoster Row, E. C.).—These reports on the different branches of chemistry are particularly suitable for enabling specialists in one branch of the science to learn the main features of progress in the other branches. The reports are short and condensed, they have been prepared by prominent scientists, and include the following titles: General and Physical Chemistry, Inorganic Chemistry, Organic Chemistry, Part I, Aliphatic Division, Part II, Homocyclic Division, Part III, Heterocyclic Division and Stereochemistry, Analytical Chemistry, Physiological Chemistry, Agricultural Chemistry and

Vegetable Physiology, Mineralogical Chemistry, and Radioactivity. H. L. W.

6. *The Progress of Scientific Chemistry in Our Own Times;* by Sir William A. Tilden. 8vo, pp. 366. London, 1913 (Longmans, Green and Co.).—This is the second edition, to which some new matter has been added, including biographical notes, of a somewhat popular discussion of the subject. The book is based on a course of "Lectures to Workingmen" and it gives a clear and excellent discussion of modern chemical principles and the discoveries that have led to their establishment. It is a very suitable book for the use of students of chemistry of all grades, and it will serve as a valuable aid to the chemical lecturer. H. L. W.

7. *The Synthetic Use of Metals in Organic Chemistry;* by Arthur J. Hale. 12mo, pp. 169. Philadelphia, 1914 (P. Blakiston's Son and Co.).—This little book of British origin discusses, as its title indicates, only those reactions of organic chemistry where metals and metallic derivatives have been utilized in the development of this branch of chemistry. Important reactions of recognized merit are discussed and illustrated fully by structural equations. A feature of the book is an appendix devoted to simple organic preparations which illustrate various applications of the metals. The general scope of the book, however, is narrow and the treatment of the subject far from complete. T. B. J.

8. *Electrical Analogue of the Zeeman Effect.*—In a series of four papers by J. Stark and his co-workers, G. Wendt and H. Kirschbaum, an account is given of some new and important phenomena exhibited by spectral lines under special conditions. In brief, the general problem was to investigate the effect (if such exists) of electric fields on spectral lines.

Transverse effect. The apparatus used was ingeniously constructed as follows. A cylindrical vacuum tube was provided with disc electrodes which were set coaxially and relatively far apart. The cathode was perforated in order to allow the canal rays to enter the region of the tube more remote from the anode. In this region a third disc electrode was fixed parallel to the cathode at a distance of 1·1 or 2·6^{mms} from the cathode. The third disc and the cathode were joined respectively to the negative and positive poles of a suitable source of constant potential. Since the perforated cathode and the neighboring disc were close together, very large potential gradients could be readily established between the electrodes. The pressure of the gas in the tube was regulated to make the cathode dark space 5 to 10 cms. long and therefore to amply surround the perforated cathode and the adjacent negative disc. When the tube proper was not excited no discharge took place between the perforated cathode and the auxiliary cathode up to, and exceeding, potential gradients of 50,000 volts per cm. When all three electrodes were simultaneously in action the canal rays ionized the gas between the juxtaposed discs

and thus gave rise to the series lines of the gas in the tube (helium, hydrogen, etc.). By this arrangement negatively charged particles passed out of the electrostatic field through the perforations in the usual cathode. A suitably placed plane window was affixed to the side of the tube with its normal at right angles to the common axis of the condenser plates (the pair of cathodes). In other words, the line of sight was perpendicular to the axis of the electrostatic field and hence to the paths of the positive ions. One typical illustration of the phenomena observed must suffice. The line Hγ was separated into seven components. Three of these were found to be polarized (electric vector) at right angles to the electric field and to have intermediate intensity. The central component of this triplet was very slightly displaced from the position of the unresolved line (electrostatic field unexcited). Outside of the triplet two stronger components of the original line were observed. Also between each pair of lines of the triplet two very faint lines were discerned. The six lines were equally spaced, in pairs, with respect to the central component of the triplet. The four lines not members of the triplet were found to be polarized parallel to the direction of the impressed electrostatic field.

Longitudinal effect. In order to have the line of sight coincident with the axis of the electric field the vacuum tube had to be remodeled as follows. Instead of a group of perforations in the usual cathode a single slit was made in the geometrical axis of revolution of the disc. The condenser plates of the electrostatic field were fastened with their plane faces parallel to the axis of the slit. The continuation of this axis passed half-way between the condenser plates. The auxiliary anode was pierced by holes so as to enable the light to reach the slit of the dispersing apparatus. It was thus possible to look along the direction of the electric field but at right angles to the paths of the canal rays. For reasons which cannot be given in this place, it was found correct to perforate the auxiliary anode but not the associated cathode. Special experiments and considerations showed that all sources of error, such as the curvature of the field, Doppler effect, etc., were negligible under the experimental conditions. Reverting to the line Hγ it turned out that the original line was resolved into a triplet whose components coincided in wave-lengths with the triplet observed in the transverse field. In all cases, the lines studied in longitudinal fields were unpolarized. This result is consistent with the theory worked out some time ago by Voigt.

Gradient effect. By varying the distances between the condenser plates and also the applied potential difference, it was a relatively simple matter to investigate the dependence of the separation of the outer components of any resolved line on the intensity of the electric field. For the hydrogen lines λ 4341 and λ 4861, and for the helium line λ 4026, a linear dependence was found both for the vibrations parallel and perpendicular to the field. The separation of the outer components of Hβ amounted to as much as 14·5 Å. U. in a field of 50,000 volts per cm. On the

other hand, the helium line at λ 4472 did not follow a linear relation. The curves corresponding to this line are slightly concave towards the axis of potential gradient. In conclusion, it may be remarked that the laws governing lines belonging to the same or to related series of the same element, or of different elements, have been as yet only partially worked out, and hence any account of their probable nature would be premature at the present time.—*Ann. d. Physik*, vol. xliii, pp. 965-1047, April, 1914. H. S. U.

9. *Secondary Standards of Wave-Length in the Infra-Red.*—By means of a Fabry and Perot interferometer A. IGNATIEFF has accurately determined the wave-lengths of one line of cadmium and two of helium. A special monochromatic filter was used to isolate the radiations under investigation. An account of the composition and construction of absorption cells for long wave-lengths is given by F. Paschen in the Annalen der Physik, No. 6, March, 1914, pages 858-860. The helium line at λ 10830 was found to be double. By using an iron-constantan thermopile in conjunction with a Paschen "Eisengalvanometer," and by plotting curves having distances between the interferometer plates as abscissæ and galvanometer deflections as ordinates (method of beats) the investigator found the separation of the components of the helium doublet to be $1{\cdot}21 \pm 0{\cdot}01$ Å. U. The wave-lengths of this doublet and of the two single lines were determined by two methods, (a) "thermopile in central zone," and (b) the quenching action of heat on a phosphorescent screen (phosphoro-photography). The final results are $10394{\cdot}66 \pm 0{\cdot}02$ Cd, $10830{\cdot}32 \pm 0{\cdot}01$ He, $10839{\cdot}11 \pm 0{\cdot}02$ He, and $20581{\cdot}31 \pm 0{\cdot}02$ He. The numbers following the double signs denote "possible" errors.—*Ann. d. Physik*, vol. xliii, p. 1117, April, 1914. H. S. U.

10. *The Electrical Conductivity and Ionization Constants of Organic Compounds;* by HEYWARD SCUDDER. Pp. 568. New York, 1914 (D. Van Nostrand Co.).—The nature and scope of the contents of this volume are made quite clear by the following quotation from the author's introductory remarks. "The *object* of this book is to present, . . . , a bibliography of all the measurements of the ionization constants and the electrical conductivity of organic compounds that have appeared in the periodical literature between the years 1889 and 1910 inclusive, together with the values of the ionization constants, and certain values of the electrical conductivity measurements." "Qualitative work is also included." "Before the year 1889, little work of value at the present time was published." "All that is of value is included here." "From 1910 to the begining of 1913, important corrections that have come to my notice have been inserted." "Beginning with 1910, full data of the entire periodical literature are published in the Tables Annuelles Internationales de Constantes et Données Numériques."

That the presentation is very complete and systematic may be inferred from the following sequence of captions: Explanation, Abbreviations, Cyclic Formulæ, Tables (pages 42-322), Formula Index (pages 323-389), Author List (2032 references), Subject In-

dex, Journal List, and Addenda. The author and the publishers deserve much credit for the enormous amount of uninteresting work necessitated by the compilation of the material and for the very clear, appropriate, and accurate typographical composition respectively. H. S. U.

11. *The Theory of Heat Radiation;* by MAX PLANCK. Translated from the second edition by MORTON MASIUS. Pp. xiv, 225, with 7 figures. Philadelphia, 1914 (P. Blakiston's Son & Co.).—In this book Planck gives a very clear exposition of his hypothesis of the "quantum of action" which has exerted a very profound influence on the recent developments of theoretical physics. The subject matter is divided into five Parts which have the following headings: I "Fundamental Facts and Definitions," II "Deductions from Electrodynamics and Thermodynamics," III "Entropy and Probability," IV "A System of Oscillators in a Stationary Field of Radiation," and V "Irreversible Radiation Processes."

The translator has increased the usefulness of the volume by adding several foot-notes, an appendix on deductions from Stirling's formula, and a commentated list of general papers which treat of the application of the theory of quanta to different branches of physics. English students who experience distraction of attention in attempting to read the original text will undoubtedly feel very grateful to Masius for the clear and accurate translation which he has given. H. S. U.

II. GEOLOGY.

1. *Virginia Geological Survey;* THOMAS LEONARD WATSON, Director. *Bulletin No. VIII, Biennial Report on the Mineral Production of Virginia during the calendar years 1911 and 1912;* by THOMAS L. WATSON. With chapters on zirconiferous sandstone near Ashland, Virginia, by Thomas L. Watson and Frank L. Hess, and geology of the salt and gypsum deposits of Southwestern Virginia by George W. Stose. Pp. 76, 2 pls., 8 figs. Charlottesville, 1913.—The variety of products mined and quarried in Virginia is indicated by the statistical tables, which include barytes, clay, coal, copper, diatomaceous earth, feldspar, gold, granite, gypsum, iron, lead, lime, limestone, manganese, paint ores, portland cement, pyrite, rutile, salt, sandstone, silver, slate, talc and zinc. The papers by Watson and Hess and by Stose, included in Bulletin VIII, have been previously published in substantially their present form as parts of Bulletin 530 of the U. S. Geological Survey. H. E. G.

Bulletin No. IX, The Coal Resources and General Geology of the Pound Quadrangle in Virginia; by CHARLES BUTTS. Prepared in coöperation with the U. S. Geological Survey. Pp. 61, 1 fig., 3 pls., map in pocket. Charlottesville, 1914.—The report on the Pound Quadrangle is the first of a series of papers on the Pennsylvanian coals of southwestern Virginia. In this

area the number of coal beds is "probably greater than elsewhere in the Appalachian coal field," and the conditions for a detailed study of the stratigraphy appear to be unusually favorable. The columnar section includes the Lee, Norton, Wise and Harlem formations, and the structure sections shown in Plate III indicate clearly the geological factors with which the coal industry is concerned. H. E. G.

2. *Florida State Geological Survey;* E. H. SELLARDS, State Geologist. *Fifth Annual Report.* Pp. 306, pls. 14, figs. 17, 2 maps. Tallahassee, 1913.—The report of the Florida Geological Survey for 1913 contains two articles of more than local importance: Origin of the Hard Rock Phosphate Deposits by E. H. Sellards, and Artesian Water Supply of Eastern and Southern Florida by E. H. Sellards and Herman Gunter. Dr. Sellard's views regarding the origin of phosphate differ from those of Wyatt, Pratt, Cox, Darton, Dall and Eldridge and rest on observations which indicate that formations later than the Vicksburg formerly extended across the phosphate fields. These formations "disintegrated *in situ* and the phosphate itself is derived from the phosphate originally widely disseminated through these formations, circulating waters being the agency by which the phosphate has been carried to its present location." H. E. G.

3. *Illinois Geological Survey;* F. W. DEWOLF, Director. *Bulletin No. 22, The Oil Fields of Crawford and Lawrence Counties;* by RAYMOND S. BLATCHLEY. Pp. 442, pls. IA–XXXI, 8 maps in case. Urbana, 1913.—In addition to an exclusive treatment of the economic aspects of the oil fields of southeastern Illinois, the author of Bulletin No. 22 discusses the stratigraphy of the Paleozoic section, and presents much detail regarding structural relations. The oil of the area is believed to have its origin in the plants entombed in the strata of Carboniferous age. H. E. G.

4. *The Ohio and Mississippi Floods of 1912;* by H. C. FRANKENFIELD. Bulletin Y, U. S. Department of Agriculture, Weather Bureau. Issued December 27, 1913. Pp. 25, diagrams I–VI, precipitation charts 35.—In the Ohio and in the lower Mississippi valleys years without floods are exceptional. Since 1815 stages of marked high water have been reached on the average once in six years. In the Mississippi above Cairo the average is once in nine years. The precipitation which directly causes the floods appears to be due to the "Southwest Type" of storm, the features of which are fairly well known. The flood of 1912 ranks first in the flood history of the lower Mississippi Valley in points of height of water, duration and amount of damage. In the analysis given by Professor Frankenfield the causes of the flood, its origin and progress, its crest stages, and the effect of levee construction, are treated in detail, and illustrated by numerous charts. The loss or damage caused by the flood of 1912 is estimated at over $78,000,000. H. E. G.

5. *New Zealand Geological Survey;* P. G. MORGAN, Director. *Bulletin No. 16 (New Series). The Geology of the Aroha Sub-*

division, Hauraki, Auckland; by J. Henderson, assisted by J. A. Bartrum. Wellington, 1913. Pp. 127, pls. I–X, 7 diagrams, 10 maps and sections.—This Bulletin No. 16, taken in connection with Bulletins Nos. 4, 10 and 15, completes the detailed mapping of the mining areas of Hauraki, Auckland. Of the 662 square miles included in the Aroha subdivision 250 are forested with Kauri and other timber. In this latitude (about 37°±S.) Kauri and mangrove find their southern limit and the factors controlling their distribution offer a fascinating ecologic problem.

Four major earth blocks have resulted from movements in late Tertiary and recent times,—movements which are responsible for the larger topographic features present. To the physiographer the complicated history of the streams traversing the Hauraki plain affords an excellent example of the changes induced by uplift and tilting.

The formations represented in the Aroha area are: (1) Recent and Pleistocene, river and estuarine deposits; (2) Tertiary, rhyolites and dacites and andesites, with fragmental deposits of several types and including lignite; (3) Jura-Triassic grauwackes and argillites. The Tertiary volcanics are fully discussed in a description which includes microscopic and chemical analyses. The gold and the silver bodies of this prosperous mining district "owe their formation to secondary concentration, by descending meteoric waters . . . of masses of propylitized rock." The controlling factors appear to be the degree and extent of the area of propylitization and the topography of the mining area. H. E. G.

Seventh Annual Report, 1912–13, Appendix C. Pp. 115–142, 3 maps.—The Director of the New Zealand Survey announces that two paleontologic papers: Materials for the Paleontology of New Zealand by Dr. J. Allen Thompson and Revision of the Tertiary Mollusca of New Zealand based on type material by Henry Sutor, are soon to appear. It is also announced that the fossil fauna and flora of Cretaceous, Jurassic and Triassic age, and also the Paleozoic faunas, are at present under examination by specialists in Europe and Australasia. Among the special reports included in Appendix C are: The Coal Possibilities of Westport Flats, by P. G. Morgan, and Geology of the Te Puke District, by J. A. Bartrum. H. E. G.

6. *Mountains. Their origin, growth, and decay;* by James Geikie. Pp. xix, 311; pls. 80, figs. 57. New York, 1914 (D. Van Nostrand Company).—This work, as stated by the author, deals with the borderland of geology and geography, the main subjects discussed being the architecture and origin of mountains. Technicalities are largely avoided with the intention of making the volume available for general reading. In conformity with this end the plates are largely photographs, excellently chosen and reproduced, and diagrams are also abundant as text-figures. Considerable space is given to the architecture of the Alps,

developing the views of Bertrand, Lugeon, and others regarding the recumbent folds and overthrust rock sheets. As most of the literature on this subject has been in French and German, this text will be a welcome addition to the English-reading public, including the intelligent summer traveler as well as the geologist.

J. B.

7. *La Géographie de Terre-Neuve;* par Robert Perret. *Préface* de M. Marcel Dubois. Pp. vi, 373; pls. 31. Paris, 1913 (Librairie Orientale et Américaine; E. Guilmoto).—A very thorough study of the geography of Newfoundland is given in this volume. Following the introduction is a chapter on the history of the geography of Newfoundland and another on the geology. The distinction between geology and geography is emphasized. Following these introductory chapters the greater part of the volume is devoted to such topics as the banks, the climate, the plants, etc. The interior of the island is described in some detail as well as the colonization of the island and the exploitation of the sea. J. B.

8. *Fossilium Catalogus. I: Animalia;* editus a F. Frech; *II: Plantae;* editus a W. Jongmans.—These indispensable catalogues should be in the hands of all paleontologists and in all geological libraries. The cost is not high considering what is given, and further, either series I or II, or the individual parts of each, may be purchased alone. For prices consult the publishers, W. Junk, Berlin W. 15, Germany. The parts at hand are:

I: Animalia. 1: F. Frech, Ammoneæ Devonicæ (Clymeniidæ, Aphyllitidæ, Gephyroceratidæ, Cheiloceratidæ). 1913. 2: W. Teppner, Lamellibranchiata tertiaria, "Anisomyaria," I. 1914. 3: C. Schuchert, Stelleroidea palaeozoica. 1914. 4: F. de Huene, Saurischia et Ornithischia triadica ("Dinosauria" triadica). 1914.

II: Plantæ. 1: W. Jongmans, Lycopodiales I. 1913. 2: W. Jongmans, Equisetales I: Actinopteris, Anarthrocanna, Annularia, Annulariopsis, Aphyllostachys. 1914. C. S.

9. *Spitsbergen Map of Prince Charles Foreland from Surveys;* by W. S. Bruce, J. Mathieson and others.—This valuable map has been published with the support of H. S. H. the Prince of Monaco; a brief description is given in the Scottish Geographical Journal, vol. xxix, November, 1913.

III. Miscellaneous Scientific Intelligence.

1. *The National Academy of Sciences.*—The annual spring meeting of the National Academy was held in Washington on April 21–23; a large number of members were in attendance. The following gentlemen were elected to membership: Francis Gano Benedict, of the Carnegie Institution of Washington; Nathaniel Lord Britton, Director of the New York Botanical Gardens; Walter Bradford Cannon, of Harvard University; Henry Herbert Donaldson, of the Wistar Institute of Anatomy,

Philadelphia; Jesse Walter Fewkes, of the Bureau of American Ethnology, Washington; Edward Curtis Franklin, Stanford University; Moses Gomberg, University of Michigan; Herbert Spencer Jennings, Johns Hopkins University; Ernest Merritt, Cornell University; Frederick Leslie Ransome, United States Geological Survey.

The list of papers presented is as follows:

W. F. Hillebrand, H. E. Merwin and Fred. E. Wright: Hewettite, metahewettite and pascoite, hydrous calcium vanadates.

J. M. Coulter: The origin of monocotyledony.

C. B. Davenport: Heredity of some emotional traits.

C. D. Walcott: Pre-Cambrian Algonkian Algæ.

F. W. Clarke: Composition of crinoid skeletons.

W. H. Howell: Causes of the clotting of the blood.

E. L. Nichols and H. L. Howes: The luminescence of kunzite.

S. J. Meltzer: Prompt distribution of convulsants in cardiectomized frogs deprived of their lymph hearts.

L. V. Pirsson: Contributions to the geology of Bermuda.

Jacques Loeb: Heterogenous hybridization.

W. J. Humphreys: On the relation between American temperatures and European rainfall.

J. P. Iddings: The physics of magmatic eruption.

John Johnston: High pressure as a factor in geologic processes.

Henry Fielding Reid: The movements of magnets caused by earthquakes.

G. P. Merrill: A history of American State Geological and Natural History Surveys.

E. L. Nichols: Biographical Memoir of Henry Morton.

W. M. Davis: Biographical Memoir of J. Peter Leslie.

Cleveland Abbe: Biographical Memoir of Charles A. Schott.

Arthur L. Day: Biographical Memoir of Miers Fisher Longstreth.

In addition to the above papers the series of lectures founded in memory of William Ellery Hale of Chicago was inaugurated by Sir Ernest Rutherford of the University of Manchester. Two lectures were delivered dealing with the Constitution of Matter and the Evolution of the Elements. The committee in charge has planned other lectures on this general subject of evolution. The second series to be given in the coming autumn will be by Dr. W. W. Campbell, Director of the Lick Observatory, who will discuss the principal theories of stellar evolution. It is proposed to invite a distinguished European geologist to give a third course of lectures at the annual meeting of the Academy in 1915; he will show how the surface features of the earth have been altered in the process of time.

2. *The Carnegie Foundation for the Advancement of Teaching. Eighth Annual Report of the* President, Henry S. Pritchett and the Treasurer, R. A. Franks. Pp. vi, 158. New York City, October, 1913.—The most important event of the past year for the Carnegie Foundation has been the establishment of a Division of Educational Enquiry, endowed in January, 1913, by a gift from Mr. Carnegie of $1,250,000. The work involved has been carried on from the beginning as an essential part of the labors of the Carnegie Foundation but it is only now that it is

provided with an independent income. The endowment alluded to has been allotted from the funds of the "Carnegie Corporation of New York" which has a capital of $128,000,000 and an income of a little more than $6,000,000. The purposes of the corporation are very broad in their beneficial work and it is specially charged with safeguarding the interests of the five Institutions with which Mr. Carnegie's name is connected and to which he has already given between eighty and ninety million dollars.

The Carnegie Foundation now has a total endowment of $15,325,000, and the expenditure for the year ending September 30, 1913, was $658,431; of this $519,440 was distributed in retiring allowances to professors, and $80,949 in pensions to their widows, a total of $600,390. Thirty-three new allowances were granted during the year, making the total in force 403; the average annual payment to an individual is $1703. The total distribution from the beginning in 1905 has been $2,936,927. A number of topics of vital interest to educational institutions and their officials are treated in this Report: as the new systems of pensions established here and in England; College entrance requirements; state regulation of higher education, etc. The subject of College catalogues is treated critically and the gentle sarcasm of the author makes it amusing as well as profitable reading. Education in Vermont is handled in a separate bulletin.

3. *The Carnegie Foundation for the Advancement of Teaching. Education in Vermont.* Bulletin No. 7, parts I and II, pp. 214. New York City, 1914.—The present Bulletin shows the work of the Carnegie Institution extended in a somewhat new direction, the results being presented here of an inquiry as to the educational situation in Vermont, undertaken at the request of the State legislature. The report advises in brief that the money now being given to the three colleges, aggregating in 1913 to about $100,000, be transferred to the public schools, on the ground that the State cannot well afford a regular State University, while the public schools, which provide the entire education of more than nine-tenths of the children, are in great need of better support. Special recommendations are as follows: "That the dozen training-classes for teachers that were established in the high schools in 1910 be multiplied, so that every new teacher in the state shall be a high school graduate with professional training. These classes graduated more than a hundred such teachers last year, and will soon be able to supply the entire four hundred that the state needs annually. The two state normal schools, the abandonment of which is recommended, have provided less than a dozen such teachers each year.

It is further recommended "that the teachers, together with a new state commissioner of education, several deputy commissioners, and a number of supervisors, gradually work out a new program of studies for the schools which, without interfering with its academic character, will relate it more closely to the

daily life of the pupils. It is recommended that the high schools include vocational courses, that there be special agricultural schools, and that the work of the State Agricultural College be made of greater value to the farmers. Further school consolidation, with transportation wherever necessary, is also recommended both for elementary and high schools, so that every community may be within reach of first-rate schools instead of scattering its money and care among a large number that are inferior."

The general questions raised in this report as to what part of the general field of education a particular College or University can best cultivate and also what are its special advantages and limitations might well be carefully considered by the Faculties of all our higher institutions.

4. *The Mining World Index of Current Literature. Vol. IV. Last half year 1913;* by GEORGE E. SISLEY, Associate Editor. Pp. 190. Chicago (Mining World Company), 1914.—This, the fourth volume of the series, is planned to embrace all important contributions, for the time specified, to the world's literature in mining, metallurgy and kindred subjects. The entries are classified under the prominent topics (e. g. the metals) and an author's index of 28 pages closes the work.

5. *Les Prix Nobel en 1912.* Pp. 69. Stockholm, 1913 (P. A. Norstedt & Söner).—This volume contains an account of the distribution of the Nobel prizes of 1912, in which year the following gentlemen were honored: in physics, Dr. Gustaf Dalen; in chemistry, Dr. Victor Grignard and Dr. Paul Sabatier; in medicine, Dr. Alexis Carrel; in literature, Dr. Gerhart Hauptmann. Portraits of these gentlemen are included and also representations of the Nobel prizes and diplomas. The addresses delivered by several of the gentlemen, to whom prizes had been awarded, at the Nobel Conférence on December 10, are also given in full.

6. *A Manual of Bacteriology;* by HOWARD S. REED. Pp. xii, 175, 46 figures. Boston and New York, 1914 (Ginn and Company).—The book is planned to suit the needs of bacteriological students in agricultural and technical schools. The subject matter is arranged in 16 sections and 15 appendixes. The sections consist of well-planned laboratory exercises with occasional explanatory paragraphs. The manual covers a large field. It deals not only with the usual phases of bacteriological technique, etc., but it also includes the study of the numerous complex physiological processes which are carried on in nature by bacteria and related organisms. Much attention is given to the subject of fermentations and other activities of microorganisms in their bearing on agriculture, baking, brewing, etc. References to the more important literature are given in conspicuous positions.

L. F. R.

Obituary.

Professor Newton Horace Winchell, formerly the state geologist of Minnesota, died on May first, after an operation in the Northwestern Hospital, Minneapolis, Minnesota. Winchell was born at Northeast, New York, December 17, 1839. In 1866 he was graduated at the University of Michigan. Before this time, however, he had done geological work on the Michigan State Survey, and three years after his graduation he became assistant state geologist. From 1870 to 1872 he was connected with the Geological Survey of Ohio, and from 1872 to 1900 served as state geologist of Minnesota; during this latter period were issued under his direction the six large volumes dealing with the geology and paleontology of the state, which are so widely known for the careful work they contain. Professor Winchell organized and edited the *American Geologist*, a highly creditable monthly periodical which appeared from 1888 to 1905, after which time it was amalgamated with *Economic Geology*. In 1902 he was president of the Geological Society of America, and he was the founder of the Minnesota Academy of Sciences. Since 1905 he had been in charge of the section of archeology of the Minnesota Historical Society, where he published last year an interesting volume entitled "The weathering of aboriginal stone artifacts. No. 1. A consideration of the paleoliths of Kansas."

Professor Winchell was planning to celebrate his golden wedding anniversary next August, and last winter at the Princeton meeting of the Geological Society of America he looked the picture of health, and as if he had many more years of activity ahead of him. He is survived by his widow, two sons, Horace V. Winchell and Professor Alexander N. Winchell, and three daughters, Mrs. U. S. Grant, Mrs. F. N. Stacey and Mrs. B. Draper Dayton.

Charles Schuchert.

Professor Charles Santiago Sanders Peirce, one of the ablest mathematicians and logicians of the time, and a man of original genius and character, died on April 19 at the age of seventy-four years. He was the son of the Professor Benjamin Peirce of Harvard University and obtained his education at this University. The greater part of his life was given to study and research though he taught for a time at Harvard and Johns Hopkins. For the past twenty-five years he had lived in the mountains near Milford, Penn.

Dr. Eduard Suess, the veteran Austrian geologist of world-wide reputation and influence, died on April 26 in his eighty-third year. A notice is deferred till a later number.

Dr. Jacques Huber, the eminent director of the Museu Goeldi at Pará, Brazil, died on February 18 in his forty-sixth year.

Robert Kaye Gray, active in technical and scientific education and one of the founders of the National Physical Laboratory, died at Brighton, England, on April 28 at the age of sixty-two years.

INDEX TO VOLUME XXXVII.*

A

Academy, National, meeting at Washington, 204, 562; Semi-centennial volume, 204.
Africa, German Expedition to Central, Botany, 122.
Agassiz, G. R., Life of Alexander Agassiz, 485.
Allen, H. S., Photo-Electricity, 348.
Allen's Commercial Organic Analysis, Davis and Sadtler, 274.
Alternating currents, Jackson, 350.
Ames, J. S., Constitution of Matter, 112.
Amphiboles, optical study, Ford, 179.
Andersen, O., binary system MgO–SiO, 487.
Anderson, W. B., Physics, 480.
Appalachian geosyncline, Upper Devonian delta of, Barrell, 87, 225.
Arctowski, H., climatical variations, 305.
Arup, P. S., Industrial Organic Analysis, 275.
Astronomy, Jacoby, 207; Newcomb-Engelmann's, 363.
— of Paradise Lost, 364.
Attraction, Mathematical Theory, Tarleton, 349.

B

Bacteriology, Reed, 565.
Barrell, J., Upper Devonian delta of the Appalachian geosyncline, 87, 225.
Barus, C., electrometry with displacement interferometer, 65; repulsion of parallel plates, 350; displacement interferometer applied to the horizontal pendulum, 501.
Bendrat, T. A., rocks of Cerro de Santa Ana, Venezuela, 268.
Benson, H. K., Industrial Chemistry, 194.
Berry, E. W., Nipa-palm in No. American Eocene, 57; date palm in Tertiary of Texas, 403.
Biology, C. S. Minot, 123.
Blake, J. M., mounting diatoms, 535.
Bloxam, C. L., Chemistry, 274.

BOTANY & BOTAN. WORKS.

Algerian Sahara, Cannon, 122.
Botany, Clute, 122.
Fungi which cause Plant Disease, Stevens, 205.
German Expedition to Central Africa, 122.
Palm in the No. American Eocene 57; Tertiary date palm in Texas, Berry, 403.
Plant Products, Chemistry of, Haas and Hill, 123.
Plants, Diseases of Tropical, Cook, 285.
Bowen, N. L., binary system MgO–SiO, 487.
Bradley, W. M., solid solutions in minerals, 339.
Brazil, Permian geology, Lisboa, 425.
— reef formations of coast, Waring, 367.
British Museum catalogues, 287.
Brown, T. C., Shawangunk Conglomerate, 464.
Burnham, S. W., Measures of Proper Motion Stars, 206.

C

Calculus, Franklin, McNutt and Charles, 113.
California, fossil dolphin, Lull, 209.
Canada, Department of Mines, 352.
Carnegie Foundation for the Advancement of Teaching, 8th Ann. Report, 563; Bulletin VII, 564.
— Institution of Washington, Yearbook, 361.
Chemical Journal, American, 207.
Chemistry, Bloxam, 274.
— in America, Smith, 555.
— Dictionary of, Thorpe, 274.
— Industrial, Benson, 194; Arup, 275.
— International Congresses of Applied, publications, 205.
— Modern Inorganic, Mellor, 476.
— Organic, Davis and Sadtler, 274; Cohen, 194; Gattermann, 477; Hale, 556.
— of Plant Products, Haas and Hill, 123.
— Progress for 1913, Annual Report, 555.
— Qualitative Analysis, Bailey and Cady, 554; Vorisek, 476.
— Quantitative Analysis, Clowes and Coleman, 275; Waddell, 111.
— Scientific, Progress, Tilden, 556.
— Theoretical, Getman, 195.

*This Index contains the general heads, BOTANY, CHEMISTRY, GEOLOGY, MINERALS, OBITUARY, ROCKS; under each the titles of Articles referring thereto are included.

CHEMISTRY.

Aluminium carbide, action upon metallic salts, Hilpert and Ditmar, 193.
Ammonium peroxides, D'Ans and Wedig, 111.
Bromine, determination, Gooch and Cole, 257.
Carbon sulphide-telluride, etc., Stock, Prætorius and Willfroth, 346.
Dimethyl phosphates of the rare earths, 475.
Esters of substituted aliphatic acids, hydrolysis, Dean, 331; Drushel, 514.
Gallium, new source, Bardel and Boulanger, 110.
Gold, double bromides, Gutbier and Huber, 346.
Heat of formation of hydrogen, Langmuir, 479.
Hydrolysis, see esters.
Iron, rusting in water, Bradbury, 273.
Magnesium chloride as crystallizing agent, Hofmann and Höschele, 345.
Metallic elements, relative abundance, Clarke and Steiger, 553.
Nickel and cobalt sulphides, Thiel and Gessner, 475.
Nitrogen, active, Tiede and Domcke, 347.
Periodates, estimation of, Müller and Wegelin, 273.
Periodic law and thermochemistry, Mixter, 519.
Radio-elements, reactions of, Fajans and Beer, 110.
Selenium, determination, Meyer, 347.
Silica, determination of, Kuzirian, 61.
Silver, spitting of, Baker, 554.
Telluric acid, use in analysis, Gooch and Cole, 257.
Titanium, separation from iron, Thornton, 173, 407.

Cheshire, Ct., "dam" at, Ward, 155.
Climatical variations, Arctowski, 305.
Coast Survey, U. S., report, 363.
Cohen, J. B., Chemistry, 194.
Cole, H. I., determination of bromine, 257.
Connecticut Birds, 484.
— Farmington Mastodon, 321.
Constants, Annual Tables, 205.
Cook, M. T., Diseases of Tropical Plants, 285.
Crystal structure shown by Röntgen rays, 277.
Currents, Alternating, Jackson, 350.

D

Dadourian, H. M., development of mechanics, 157.
Daly, R. A., Igneous Rocks, 358.
Day, A. L., determination of mineral and rock densities at high temperatures, 1; volcanic activity and water, 357.
Dean, E. W., hydrolysis of esters of aliphatic acids, 331.
Density determinations at high temperatures, Day, Sosman and Hostetter, 1.
Diatoms, mounting, Blake, 535.
Drew, G. A., Zoology, 123.
Drushel, W. A., hydrolysis of esters of aliphatic acids, 514.

E

Eakle, A. S., wilkeite and okenite, California, 262.
Earth's crust, changes in level, Fisher, 199.
Eastman, C. R., von Zittel's Paleontology, 282.
Eaton, G. F., vertebrate fossils of Ayusbamba, Peru, 141.
Electrical Congress, International, 288.
Electricity, Rays of Positive, Thomson, 347.
Electrometry with displacement interferometer, Barus, 65.
Electrons, mass of moving, Neumann and Schaefer, 198.
Electroscope, Wilson, Farwell, 319.
Energy, Sources of, Gibson, 480.
Engineers, Tables, etc., for, Ferris, 365.
Evolution, Herbert, 120; Schmucker, 119.
Explosives, measurement of pressure from, Hopkinson, 277.

F

Fabre, Poet of Science, Legros, 284.
Farmington, Ct., mastodon, 321.
Farrington, O. C., meteorites versus the earth, 200.
Farwell, H. W., Wilson tilted electroscope, 319.
Ferguson, J. B., molybdenum in rocks, 399.
Fisher, O., changes in level of the Earth's crust, 199.
Floods, Ohio and Mississippi, of 1912. Frankenfield, 560.
Florida geol. survey, 560.
Foote, H. W., solid solutions in minerals, 339.

Foote, W. M., new meteoric iron from Mt. Edith, West Australia, 391.
Ford, W. E., optical study of the amphiboles, 179.
France, Minéralogie, Lacroix, 204.
Franklin Institute, Cresson medal, 365.

G

Geikie, J., Mountains, 561.

GEOLOGICAL REPORTS.

Canada, 352.
Florida, 560.
Illinois, 203, 560.
Iowa, 117.
Maryland, 203.
New Jersey, 354.
New Zealand, 560.
Oklahoma, 204.
Pennsylvania, 353, 354.
United States, Niagara folio, 354; other publications, 280; 34th annual report, 280.
Virginia, 559.
West Virginia, 117.

GEOLOGY.

Alexandrian series, affinities, Keyes, 254; in Illinois, Savage, 203.
Algæ, calcareous, in Paleozoic rocks, Garwood, 203.
Coal bed, parting in a, Rogers, 299.
Coal beds, formation of, Stevenson, 116.
Conemaugh formation in Ohio, Condit and Mark, 114.
Cystidea, Caradocian, Bather, 115.
"Dam" at Cheshire, Conn., Ward, 155.
Devonian of Maryland, 203.
— Upper, delta of the Appalachian geosyncline, Barrell, 87, 225.
Dolphin, fossil, from California, Lull, 209.
Earth's crust, changes in level, Fisher, 199.
Eocene, No. American, Nipa-palm in, Berry, 57.
Finger Lakes in Ohio, Hubbard, 444.
Fossilium Catalogus, Frech and Jongmans, 562.
Fossil beds of Ayusbamba, Peru, Gregory, 125; Eaton, 141.
Mammals, Land, Scott, 483.
Mammut Americanum, in Connecticut, Schuchert and Lull, 321.
Niagara folio, New York, Kindle and Taylor, 354.
Nordingra region geology, Sorbal, 116.
Oriskany formation in Maine, Pirsson and Schuchert, 221.
Paleontology of Trinidad, Maury, 115.
Paleozoic glaciation, late, Lahee, 316.
Permian geology of Brazil, Lisboa, 425.
Reef formations of coast of Brazil, 367.
Rodadero of Cuzco, Peru, Gregory, 289.
San Francisco district, Utah, Geology and ore deposits, Butler, 121.
Spitzbergen, geology, Holtedahl, 415, map, 562.
Tertiary of Eastern Texas, date palm, Berry, 403.
Vertebrates, Permo-Carboniferous, New Mexico, Case, Williston and Mehl, 117.
Volcanic field, the San Franciscan, Robinson, 202.
— phenomena, diagram for, Perret, 48
White Mountains, N. H., glacial cirques in, Goldthwait, 451.
Getman, F. H., Chemistry, 195.
Gibson, A. H., Sources of Energy, 480.
Glaciation, Paleozoic, Lahee, 316.
Glacier Commission, International, Rabot and Mercanton, 282.
Goldsberry, J. P., composition of bornite, 539.
Goldschmidt, V., Atlas der Krystallformen, 284.
Goldthwait, J. W., old graded upland of the White Mountains, 451.
Gooch, F. A., Determination of bromine, 257.
Gravity, Anomalies of, Gilbert, 356.
Gregory, H. E., Ayusbamba, Peru, fossil beds, 125; the Rodadero, Cuzco, Peru, 289.

H

Hawaii, molybdenum in rocks of, Ferguson, 399.
— volcanic phenomena, Day, 357.
Heat Radiation, Theory of, Planck and Masius, 559.
Herbert, S., Evolution, 120.
Heredity and Memory, Ward, 123.
Hintze, C., Mineralogie, 204.
Holtedahl, O., geology of Spitzbergen, 415.
Hostetter, J. C., density determinations at high temperatures, 1.
Hubbard, G. D., Finger Lake bed in Ohio, 444.

I

Illinois geol. survey, 560.
Interferometer, displacement electrometry with, Barus, 65; and horizontal pendulum, Barus. 501.
Ionization constants, Scudder, 558.
Iowa geol. survey, 117.
Jackson, D. C. & J. P., Alternating Currents, 350.
Jacoby, H., Astronomy, 207.
Johannsen, A., Petrographic Methods, 482.

K

Kansas Paleoliths, Winchell, 124.
Keyes, C., affinities of the Alexandrian Series, 254.
Kraus, E. H., composition of bornite, 539.
Krystallformen, Atlas, vol. II, Goldschmidt, 284.
Kunz, G. F., Curious Lore of Precious Stones, 122.
Kuzirian, S. B., correcting silica for included salts, 61.

L

Lacroix, A., Minéralogie de la France et ses Colonies, 204.
Lahee, F. H., late Paleozoic glaciation, 316.
Land, Descriptions of, Cautley, 356.
Legros, C. V., Fabre, Poet of Science, 284.
Library of Congress, report, 287.
Lisboa, M. A. R., Permian geology of Northern Brazil, 425.
Lull, R. S., fossil dolphin from California, 209; Mammut Americanum in Connecticut, 321.

M

Magnesium silicates, formation, Bowen and Andersen, 487.
Maine, Oriskany formation in, Pirsson and Schuchert, 221.
Margerie, E. de, work of Suess, 357.
Maryland, Devonian of, 203.
Mastodon at Farmington, Ct., 321.
Matter, Constitution of, Ames, 112.
Mechanics, development of, Dadourian, 157.
— of Particles, Prescott, 112.
Mellor, J. W., Modern Inorganic Chemistry, 476.
Meteorite, iron, Mount Edith, West Australia. Foote, 391.
Meteorites, composition, Farrington, 200.
Milton's Astronomy, 364.
Mineralogie, Hintze, 204.
Minéralogie de la France, Lacroix, 204.
Minerals, solid solution in, Foote and Bradley, 339.

MINERALS.

Amphiboles, optical study, 179. Arsenopyrite, Tenn., 45.
Bornite, composition, 539.
Calcite, 341. Clinoenstatite, formation, 487. Cristobalite, 21, 487.
Deeckëite, 359. Dolomite, 343.
Epidesmine, 360.
Forsterite, formation, 487.
Graphite, density of, 10.
Hodgkinsonite, 360.
Kobaltnickelpyrite, 361.
Maucherite, 360.
Nickel ores, 121.
Okenite, California, 266.
Periclase, formation, 487. Pisanite, Tenn., 40.
Quartz, density of. 15.
Staurolite, Tenn. 46.
Temiskamite, 170.
Wilkeite, California, 262.
Yukonite, 360.
Zircons, color of, 275.
Mines, U. S., Bureau of, annual report, 351; Department of, Canada, 352; New Zealand, 561; South Africa, 354.
Minot, C. S., Biology, 123.
Mississippi, mud lumps at the mouths of, Shaw, 356.
Mixter, W. G., thermochemistry and the periodic law, 514.
Mollusca, Life of, Woodward, 283.
Mountains, Origin, etc., Geikie, 561.
Murray, Sir John, The Ocean, 355.

N

Napier Tercentenary, 288.
Neon, series lines of, Rossi, 197.
Newcomb-Engelmann's Astronomy, 363.
Newfoundland, Perret, 562.
New Jersey geol. survey, 354.
New Mexico, Permo-Carboniferous vertebrates, Case, Williston, etc., 117.
New Zealand, geol. survey, 560.
Niagara folio, 354.
Nobel Prizes, 1912, 565.

O

OBITUARY.

Bailey, W. W., 366. Ball, R. S., 208. Bevan, P. V., 208. Bloxam, W. P., 208.
Chandler, S. C., 208. Clarke, A. R., 366.
Fritsch, A. 124.

Gill, Sir D., 288. Gray, R. K., 566, Gunther, A., 366.
Hill, G. W., 486. Holden, E. S., 366. Huber, J., 566.
Lawrence, Sir T., 208.
Mercalli, G., 366. Minchin, G. M., 486. Mitchell, S. W., 208. Murray, Sir J., 366.
Peirce, B. O., 208. Peirce, C. S. S., 566. Potonié, H., 124. Poynting, J. H., 486.
Robinson, C. B., 208. Rosenbusch, H., 288.
Salinas, A., 486. Suess, E., 566.
Tchernycheff, T., 288.
Upton, W., 208.
Winchell, W. N., 566. Woodward, H. B., 366.
Observatory, Yerkes, observations at, Burnham, 206,
Ocean, The, Murray, 355.
Ohio, Conemaugh formation in, Condit and Mark, 114.
— Finger Lakes, Hubbard, 444.
— Floods of 1912, 560.
Oklahoma geol. survey, 204.
Organic Compounds, Electrical Conductivity, etc., Scudder, 558.

P

Paleoliths of Kansas, Winchell, 124.
Paléontologie Végétale, Pelourde, 284.
Paleontology, Text-book, von Zittel and Eastman, 282.
Palm, date, in the Tertiary of Eastern Texas, Berry, 403.
— Nipa, in No. Amer. Eocene, Berry, 57.
Pennsylvania, Topographic and Geologic Survey, 353, 354.
Perret, F. A., diagram of volcanic phenomena, 48.
Perret, R., Geography of Newfoundland, 562.
Peru, Ayusbamba fossil beds, Gregory, 125, Eaton, 141; the Rodadero, Cuzco, Gregory, 289.
Petrographic Methods, Johannsen, 482.
Phillipine Islands, Bureau of Science, Annual report, Cox, 285.
Photoelectric effect of potassium, Hallwachs and Wiedmann, 478.
— suppression of, Fredenhagen and Küstner, 276.
Photo-Electricity, Allen, 348.
Physics, Anderson, 480.
Pirsson, L. V., Oriskany formation in Maine, 221.
Plates, parallel, repulsion of, Barus, 350.
Precious Stones, Kunz 122.
Prescott, J., mechanics, 112.
Pressure in detonation of high explosives measured, Hopkinson, 277.

Q

Quartz glass, thermal expansion, Scheel and Heuse, 479.

R

Radioactive origin of color of, zircons, Strutt, 275.
Radio-elements, Chemistry of, Soddy, 349.
Reed, H. S., Bacteriology, 565.

ROCKS:

Bergalite, 359.
Cerro de Santa Ana, Venezuela, rocks of, Bendrat, 268.
Diabase, density at high temperatures, 25.
Granite, density at high temperatures, 22.
Molybdenum in rocks of Hawaii, Ferguson, 399.
Igneous, Daly, 358.
Värnsingite, Sweden, Sobral, 116.
Rogers, A. T., wilkeite and okenite from California, 262.
Rogers, G. S., parting in a coal bed, 299.
Röntgen rays, spectrography, de Broglie, 477.
— — crystal structure shown by, de Broglie, 277.

S

San Franciscan volcanic field, Robinson, 202.
Schmucker, S. C., Evolution, 119.
Schuchert, C., Oriskany formation in Maine, 221; Mammut Americanum, Connecticut, 321.
Science, Cambridge Manuals of, 365.
— Who's Who in, 365.
Scott, W. B., Land Mammals, 483.
Scudder H., Electrical Conductivity of Organic Compounds, 558.
Seismology, Modern, Walker, 349.
Shawangunk conglomerate, Brown, 464.
Smith, E. F., Chemistry in America, 555.
Smithsonian Institution, report, 286.
Soddy, F., Chemistry of Radio-Elements, 349.
Solid solution in minerals, Foote and Bradley, 339.

Solubilities at the critical temperatures of solvents, Friedrichs, 194.
Sosman, R. B., density determinations at high temperatures, 1.
South Africa, Mines Department, 354.
Spectrography of Röntgen rays, de Broglie, 477.
Spitzbergen, geology, Holtedahl, 415; map, 562.
Stars, Measures of Proper Motion, Burnham, 206.
Stevens, F. L., Fungi which cause Plant Disease, 205.
Stevenson, J., coal bed formation, 116.
Suess, E., La Face de la Terre, 357.
Sulphur, selenium, etc., fluorescence of vapors, Steubing, 196.
Sun, oxygen in, Runge and Paschen, 195.
— total eclipse of 1914, effect on the propagation of electric waves, 480.

T

Tarleton, F. A., Mathematical Theory of Attraction, 349.
Terre, La Face de la, Suess, 357.
Thermochemistry and the periodic law, Mixter, 514.
Thomson, J. J., Rays of Positive Electricity, 347.
Thornton, W. M., separation of titanium from iron, 173, 407.
Thorpe, E., Dictionary of Applied Chemistry, 274.
Toads, poison of, Wieland and Weil, 111.
Trigonometry, Kenyon and Ingold, 364.
Trinidad, Paleontology, Maury, 115.
United States, Bureau of Mines, 351.
— — Coast Survey, 363.
— — Geol. Survey, 34th annual report, 280; Niagara folio, 354; other publications, 280.

V

Van Horn, F. R., pisanite and arsenopyrite, Tennessee, 40.
Venezuela, geology, Bendrat, 268.
Vermont, education in, 564.
Verrill, A. E., nomenclature of certain starfishes, 483.
Victoria Memorial Museum, 283.
Virginia geol. survey, 559.
Volcanic activity and water, Day and Shepherd, 357.
— phenomena, diagram for, Perret, 48.
Vorisek, A., Qualitative Chemical Analysis, 476.
Vulkanologie, Zeitschrift für, 357.

W

Waddell, J., Quantitative Analysis, 111.
Walker, G. W., Modern Seismology, 349.
Walker, T. L., temiskamite, 170.
Ward, F., the "dam" at Cheshire, Conn., 155.
Waring, G. A., reef formations of the coast of Brazil. 367.
Water, Artesian, of Australia, 355.
Wave-length in the infra-red, Ignatieff, 558.
West Virginia geol. survey, 117.
White Mountains, N. H., glacial cirques in, Goldthwait, 451.
Who's Who in Science, 365.
Woodward, B. B., Life of the Mollusca, 283.

Z

Zeeman effect, electrical analogue, Stark, 556.
Von Zittel, Paleontology, 282.

ZOOLOGY and ZOOL. WORKS.

Birds of Connecticut, Sage, Bishop and Bliss, 484.
Copepoda, British Parasitic, Scott, 124.
Lepidoptera Phalænæ, Hampson, 287.
Mollusca, Life of, Woodward, 283.
Starfishes, nomenclature, Verrill, 483.
Tunicata, Bibliography, 1469–1910. Hopkinson, 124.
Zoology, Invertebrate, Drew, 123.

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CONTENTS.

Page

ART. XL.—The Binary System MgO-SiO_2; by N. L. BOWEN and OLAF ANDERSEN 487

XLI.—Application of the Displacement Interferometer to the Horizontal Pendulum; by C. BARUS 501

XLII.—Hydrolysis of Esters of Substituted Aliphatic Acids; by W. A. DRUSHEL 514

XLIII.—Thermochemistry and the Periodic Law. Heats of Combination; Linear Functions of the Atomic Weights of Related Elements; by W. G. MIXTER 519

XLIV.—Picking Out and Mounting Diatoms; by J. M. BLAKE 535

XLV.—Chemical Composition of Bornite and its Relation to Other Sulpho-Minerals; by E. H. KRAUS and J. P. GOLDSBERRY 539

SCIENTIFIC INTELLIGENCE.

Chemistry and Physics.—Relative Abundance of Several Metallic Elements, F. W. CLARKE and G. STEIGER, 553.—Spitting of Silver, H. B. BAKER: Laboratory Guide to the Study of Qualitative Analysis, E. H. S. BAILEY and H. P. CADY, 554.—Chemistry in America, E. F. SMITH: Annual Reports of the Progress of Chemistry for 1913, 555.—Progress of Scientific Chemistry in Our Own Times, W. A. TILDEN: Synthetic Use of Metals in Organic Chemistry, J. HALE: Electrical Analogue of the Zeeman Effect, J. STARK, 556.—Secondary Standards of Wave-Length in the Infra-Red, A. IGNATIEFF: Electrical Conductivity and Ionization Constants of Organic Compounds, H. SCUDDER, 558.—Theory of Heat Radiation, M. PLANCK, 559.

Geology—Virginia Geological Survey, 559.—Florida State Geological Survey: Illinois Geological Survey: Ohio and Mississippi Floods of 1912, H. C. FRANKENFIELD: New Zealand Geological Survey, 560.—Mountains; their Origin, Growth, and Decay, J. GEIKIE, 561.—La Geographié de Terre-Neuve. R. PERRET: Fossilium Catalogus: Spitsbergen Map of Prince Charles Foreland from Surveys, W. S. BRUCE, J. MATHISON, etc., 562.

Miscellaneous Scientific Intelligence—National Academy of Sciences, 562.—Carnegie Foundation for the Advancement of Teaching: Eighth Annual Report of the President, HENRY S. PRITCHETT, 563.—Carnegie Foundation for the Advancement of Teaching; Education in Vermont, 564.—Mining World Index of Current Literature, G. E. SISLEY: Les Prix Nobel en 1912: Manual of Bacteriology, H. S. REED, 565.

Obituary—N. H. WINCHELL: C. S. S. PEIRCE: E. SUESS: J. HUBER: R. K. GRAY, 566.

INDEX TO VOLUME XXXVII, 567.

3185

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