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The Society issues a single serial octavo publication entitled BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA. This serial is made up of *proceedings* and *memoirs*, the former embracing the records of meetings, with abstracts and short papers, list of Fellows, etcetera, and the latter embracing larger papers accepted for publication. The matter is issued as rapidly as practicable, in covered brochures, which are at once distributed to Fellows and to such exchanges and subscribers as desire the brochure form of distribution. The brochures are arranged for binding in annual volumes, which are elaborately indexed. To this date ten volumes have been published.

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[*] Bearing the imprint [“ From Bull. Geol. Soc. Am., Vol. 10, 1898.”]

† Fractional pages are sometimes included.

CORRECTIONS AND INSERTIONS

All contributors to volume 10 have been invited to send in corrections and insertions to be made in their compositions, and the volume has been scanned with some care by the Editor. The following are such corrections and insertions as are deemed worthy of attention:

Page 351, plate 33, figure 3; *for* "figure 1" *read* figure 2
" 351, lines 11 and 12 from bottom; strike out words "shown on plate 33, figure 1, and"
" 357, line 13 from top; *for* "figure 2" *read* figure 1
" 358, " 14 " " ; *for* "figure 3" *read* figure 2
" 435, " 24 " " ; *for* "every" *read* ever
" 435, " 24 " " ; *for* "read" *read* ready
" 453, " 2 " bottom; *for* "H. H. Ami" *read* H. M. Ami
" 453, " 19 " " ; *for* "xi, 1883, pp. 107–435," *read* ix, 1881, pp. 18–46
" 455, " 7 " " ; *for* "†" *read* ‡
" 458, " 1 at bottom of page; *for* "part iii" *read* 3d series
" 458, " 1 " " ; *for* "pp. 14, 15" *read* pp. 31, 32
" 460, " 4 from bottom; *for* "pr. 28" *read* p. r28
" 480, " 14 " " ; *for* "M. A. Wadsworth" *read* M. E. Wadsworth
" 495, heading; *for* "Bog" *read* Bag
" 495, 4th line; " " " "
" 496, 13th " ; " " " "
" 497, 9th " ; " " " "
" 497, 36th " ; " " " "
" 497, 39th " ; " " " "
" 497, 43d " ; " " " "
" 502, line 8 from top; *for* "zosite" *read* zoisite
" 503, " 16 " bottom; *for* "reproduction" *read* production

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 10, PP. 1-20 JANUARY 28, 1899

PROCEEDINGS OF THE TENTH SUMMER MEETING, HELD AT BOSTON, MASSACHUSETTS, AUGUST 23, 1898

HERMAN LE ROY FAIRCHILD, *Secretary*

CONTENTS

SESSION OF TUESDAY, AUGUST 23

The Society was called to order at 10.30 o'clock a m, in the Lecture Hall of the Boston Society of Natural History. In the absence of President Stevenson, the First Vice-President, Professor B. K. Emerson, presided throughout the meeting. By mutual arrangement the geological section (Section E) of the American Association for the Advancement of Science had temporarily given the use of its time and meeting place to this session of the Geological Society.

Announcement was made of the death of Dr James Hall, the first President of the Society, and Vice-President Emerson spoke of the life and work of Doctor Hall and of the recognition of his labors and the honors paid him during his later years in both America and Europe. Remarks were also made by Professor H. L. Fairchild, speaking in behalf of Section E of the American Association and referring especially to the fact of Doctor Hall being the last representative of the first generation of American geologists; by Dr H. C. Hovey, speaking in personal reminiscence, and by Professor W. H. Niles, referring to Doctor Hall's youth and his eagerness for knowledge.

After some announcements by the Secretary relating to the work of the Society, by Mr Warren Upham concerning the program of the week, and by Professor W. H. Niles in behalf of the Boston Society of Natural History and the Local Committee, the reading of papers was declared in order.

The first paper upon the program was

SOME FEATURES OF THE STATEN ISLAND DRIFT, NEW YORK

BY ARTHUR HOLLICK

[*Abstract*]

Topographically Staten island, New York, may be divided into two parts—a hill region at the northeastern end, due to the ridge of serpentine which extends from New Brighton, at the extremity nearest to New York city, to Richmond, at about the center of the island, and a plain region which occupies the rest of the area.

The eastern and southern borders of the hill region are precipitous, reaching a maximum elevation of about 375 feet on Todt hill, at a distance of about a mile from the southern border, and thence sloping irregularly northwestward until tide-level is reached, at the waters of the Kill von Kull and Staten Island sound, which separate the island from the adjacent mainland of New Jersey.

The elevations throughout the plain region are due to morainal hills, which have a maximum elevation of about 170 feet at Woodrow and near Fort Wadsworth.

The frontal moraine extends in an irregular line from the Narrows, at Fort Wadsworth, to Tottenville, opposite Perth Amboy, New Jersey.

Two areas of the island are driftless. One of these areas is in the vicinity of New Dorp and Garrettsons, where the moraine bends northward and rests upon the serpentine ridge, forming a prominent sinus immediately south of the highest point on the ridge. The other is a similar but much smaller area in the vicinity of Tottenville.

These main facts were described by Dr N. L. Britton some years ago in a paper on the geology of the island, read before the New York Academy of Sciences April 4, 1881, and published in the Annals, volume ii, pages 161–182; but since that time many additional facts have been brought to light, especially in regard to the character of the morainal material and the structure of the moraine.

Lithologically the boulders have been more or less satisfactorily identified with prominent rock outcrops northward, the most abundant being Triassic trap and red shale and sandstone, which latter give a prevailing red color to all the morainal soil. Lithological determinations, however, are not always conclusive as to geological age, especially in the case of sedimentary rocks, and for this reason every fossiliferous boulder found was carefully examined, and all fossils contained in each were determined, if possible.

This work has extended over a period of about eighteen years, and we now have from the Staten Island drift a list of about 125 Paleozoic, about 50 Mesozoic, 2 Tertiary, and 1 Quaternary species definitely identified, besides considerable more

material too fragmentary or poorly preserved for accurate determination. From an examination of these fossils we are able to say with absolute certainty that every geological horizon in the Paleozoic, from the Potsdam to the Hamilton, is represented in our drift boulders, and in the Mesozoic both Triassic and Middle Cretaceous. The Tertiary is but sparingly present, but is probably upper Miocene or Pliocene.

There are, therefore, two important breaks in the sequence—one between the Devonian and the Triassic and another between the Triassic and the middle Cretaceous. Carboniferous Jurassic and Lower Cretaceous rocks are entirely wanting. If, now, we take the compass direction of the glacial striæ on Staten island, which have been determined to be about north 13 west to north 20 west, and extend them northward, they may be seen to cross the outcrops of the several horizons whose fossils have been found in the drift material, while, on the other hand, throughout the same region to the northward no indication of either Carboniferous Jurassic or Lower Cretaceous rocks has ever been found.

It is probably not necessary to quote the entire list of fossils, but it may be of interest to know that the majority of the Paleozoic species are Lower Helderberg in age, with Oriskany and Schoharie next.

Atrypa reticularis, L.; *Eatonia peculiaris*, Conr.; *Fenestella nervia*, Hall; *Meristella nasuta*, Conr.; *Spirifer arrectus*, Hall; *S. arcuosus*, Conr.; *S. macropleurus*, Conr.; *Stropheodonta beckii*, Hall, and *Strophomena rhomboidalis*, Wahl., are among the most abundantly represented species of brachiopods.

The only Triassic species is an *Equisetum*, provisionally determined as *E. rogersii*, Schimp. The Cretaceous fossils are all plants, with the exception of seven mollusks. The two Tertiary species are plants, and the one Quaternary is a mastodon's tooth.

There are also some features of the drift worth noting, besides those relating to the character of the material.

The structure of the moraine where it rests on the serpentine ridge is different from the structure of that part which rests on the plain region. In the former locality it is composed entirely of transported material brought from the mainland, and consists of glacial till, gravels, and occasional deposits of clay. In the latter locality, however, it consists of a core of contorted Cretaceous strata, moved but little from their original position in the island, on top of which the true morainal débris rests. This character of the moraine on the plain region is identical with its character to the eastward, on Long island, Block island, Marthas Vineyard, and the Elizabeth islands, and is manifestly due to a squeezing upward of the incoherent strata of the coastal plain by the advancing ice-front and then to the deposition of the glacial debris over the contorted ridge thus formed.

Incidentally these facts also prove, or at least strongly indicate, that no Cretaceous strata ever existed to the north of the serpentine ridge of the island, as no fragment of material which could be even provisionally identified as Cretaceous in age has ever been found in that portion of the moraine which rests on the ridge, whereas it is abundant throughout the moraine in the plain region.

Finally, it may be of interest to note how the preglacial topography modified the advance and direction of the ice at one particular point. If the course of the moraine is traced, it will be found that the most prominent northward-extending sinus in the moraine is immediately south of the highest point on the serpentine ridge. This indicates almost conclusively that the high ridge checked the advance of the ice and caused it to flow eastward toward Fort Wadsworth and westward toward Tottenville and Princes bay, thus assisting in piling up the immense accumulations of drift which are found near these localities.

The main feature, however, of this investigation was the determination of the fossils in the boulders, a work which, I believe, has never before been attempted upon such an extensive scale or extended through such a long period of time.

In the discussion remarks were made by J. C. Smock, B. K. Emerson, and the author.

In the absence of the author the next paper was read by title, as follows:

LOESS DEPOSITS OF MONTANA

BY N. S. SHALER

The following paper was then presented:

GLACIAL WATERS IN THE FINGER LAKES REGION OF NEW YORK

BY H. L. FAIRCHILD

The paper was discussed by J. W. Spencer, A. C. Lane, G. F. Wright, and the author. It is printed in full in this volume.

The next paper was read by title, as follows:

STRATIFICATION OF GLACIERS

BY HARRY FIELDING REID

[*Abstract*]

A controversy between Agassiz and Forbes arose about 1841 as to the meaning of the banded structure seen on the surface of glaciers, the former contending that it marked the outcrops of strata, and the latter that it was a peculiarity of glacial ice, independent of stratification.

There has always been great difficulty in deciding between these two views in particular cases, it being so very difficult, and indeed in many cases impossible, to follow the stratification from the névé field to the lower part of the glacier.

For the last two summers I have given particular attention to this subject on some of the Swiss glaciers. I succeeded in following the stratification on the Forno glacier practically to its lower end, and saw that the outcrops always retained their irregular outline, and that what has been considered the stratification at the end of this glacier is something else, probably closed crevasses.

I also examined the Miage and Brenva glaciers, on the south side of Mont Blanc, which were carefully studied by Forbes. The blue bands there are beautifully developed, and show without the slightest doubt that they are absolutely independent of stratification.

In unweathered sections of a glacier it is usually not very difficult to distinguish between the blue bands and stratification. Their appearances after exposure to the weather are frequently so nearly alike that it is quite impossible to distinguish between them.

Lantern slides were used to show the appearance of the strata and blue bands in different parts of the glacier. The paper will be printed in the Journal of Geology.

The following paper was then read:

EVIDENCES OF EPEIROGENIC MOVEMENTS CAUSING AND TERMINATING THE ICE AGE

BY WARREN UPHAM

Contents

INTRODUCTION

In our endeavor to ascertain the causes of the unique Ice age, forming the latest completed period of the geologic record, we receive from Lyell, Dana, and Le Conte the recognition of three great vertical movements, now denominated epeirogenic, which were experienced by each of the three great regions of the earth that are overspread by glacial drift, namely, the northern half of North America, the northwestern half of Europe, and Patagonia. Their series of epeirogenic movements in each case were, first, a preglacial general uplift to a vertical extent measured by the depths of their fiords and submerged valleys, that is, 1,000 to 8,000 feet above their present heights; second, a general depression in the Champlain epoch, closing the Ice age, to levels somewhat lower than now; and, third, a recent general re-elevation, varying in vertical amount up to at least 600 feet in North America, nearly as much in Patagonia, and about 1,000 feet in Scandinavia. The purpose of the present paper is to review the evidences of these epeirogenic movements in North America and Europe, and to inquire whether they were probably sufficient, in their influence on climatic conditions, to cause, by the high land altitude, the accumulation of the ice-sheets of these continents, and by the ensuing depression, to bring the comparatively sudden end of the Glacial period, with the mainly rapid, though fluctuating, departure of the ice-sheets and deposition of their drift.

Since the announcement by Dana, more than forty years ago, of the threefold oscillations of this continent respectively preceding, during, and after its glaciation, detailed hydrographic surveys of submerged valleys on both our Atlantic and Pacific coasts have demonstrated a vertical extent of the preglacial uplift far exceeding its known amount when the attention of geologists was thus first directed to it. No doubt need be longer entertained that its climatic effect could and did induce the general glaciation of the cool temperate and in part still frigid northern half of our continent, which, excepting the greater part of Alaska (probably exempted from so high uplift), bore an ice-sheet of at least 4,000,000 square miles in area and from one mile to probably two miles in thickness.

Preglacial high Elevation known by Fiords and submerged Valleys

WEST COAST OF NORTH AMERICA

It was about one year ago that Professor George Davidson published his collected observations of submerged valleys on the coast of California and Lower California, as they were revealed by the soundings of the United States Coast Survey.[*] From cape Mendocino southward along a distance of about 950 miles, the submerged 100-fathom plateau, mostly five to fifteen miles wide, adjoining the present shore, is indented by frequent deeply eroded old river valleys, some of which are continuations of present valleys on the land, while others are distinctly traced from the verge of the submerged plateau inward to distances of only a mile, or even less than a quarter of a mile, from the shore at projecting points where no land valley now exists. About twenty of these submarine valleys are mapped by Davidson, mostly ranging from 2,000 to 3,000 feet in depth at the verge of the plateau, which on each side of the valley has a general depth of only 100 fathoms (600 feet), with steep descent from this submerged former land margin into the abyssal ocean. But the maximum extent of the epeirogenic uplift at the time of erosion of these valleys, as known by their deepest example, about a dozen miles north of Monterey, was at least 868 fathoms (5,208 feet), this sounding of the Monterey submerged valley being obtained in its deep seaward continuation, about five miles beyond the general 100-fathom submarine contour and some twenty miles offshore. Within three miles on each side there the sea bed is less than 3,000 feet deep. In their general width, steepness of inclosing slopes, and occasional tributary branches, these valleys have the usual forms of subaerial erosion; so that to my mind they admit no other interpretation than that this large part of the west side of North America was for a considerable time raised 3,000 to 5,000 feet above its present altitude. Before that time, for some preceding and apparently longer period, the land altitude had been about 600 feet higher than now, permitting the coast to be built out by fluvial and marine deposition to the verge of the submarine plateau. The great uplift, according to Le Conte's discussion of previous papers by Davidson on this subject, took place during Late Pliocene and Pleistocene time, its culmination being attended with the continental glaciation.[†]

The Californian submerged valleys lie south of the glaciated area, excepting as that was represented by the anciently extended glaciers of the Sierra Nevada and other more eastern high ranges of our great Cordilleran belt; but the continental elevation known for California doubtless was also continuous, in a varying, but everywhere large, vertical amount, far to the north, through Oregon, Washington, British Columbia, and southern Alaska. From Puget sound northward the fiord-indented coast, with its bordering series of many mountainous islands, separated by channels that are continuations of the fiords, testify of such a formerly high

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[*] Proceedings of the California Academy of Sciences, third series, Geology, vol. i, pp. 73–103, with plates iv–xii, June 26, 1897. See also the more recent paper by Harold W. Fairbanks, "Oscillations of the Coast of California during the Pliocene and Pleistocene" (Am. Geologist, vol. xx, pp. 213–245, October, 1897), in which the literature of this subject, including earlier papers by Davidson, Le Conte, Lawson, and others, is carefully reviewed.

[†] Bull. Geol. Soc. Am., vol. 2, 1891, pp. 323–330.

elevation of the country along an areal extent surpassing that revealed south of cape Mendocino by soundings.

INTERIOR OF NORTH AMERICA

In the Mississippi basin, from the evidence of river currents much stronger than now, transporting Archean pebbles from near the sources of the Mississippi to the shore of the gulf of Mexico, Professor E. W. Hilgard thinks that the preglacial uplift, inaugurating the Ice age, was 4,000 to 5,000 feet more in the central part of the continent than at this river's mouth.*

ATLANTIC BORDERS OF THE UNITED STATES AND CANADA

On the east side of our continent, its bordering submarine plateau, much wider than on our Pacific coast, is cut by submerged valleys, which, if raised above the sealevel, would be fiords or canyons. These can be no other than river-courses eroded while the land stood much higher than now ; and its subsidence evidently took place in a late geologic epoch, else the channels would have become filled with sediments. Their most instructive example is the continuation of the Hudson River valley, which has been traced by detailed hydrographic surveys to the edge of the steep continental slope at a distance of about 105 miles from Sandy Hook. Its outermost 25 miles are a submarine fiord 3 miles wide and from 900 to 2,250 feet in vertical depth measured from the crests of its banks, which with the adjoining flat area decline from 300 to 600 feet below the present sealevel. The deepest sounding in this fiord is 2,844 feet.†

Again, as noted by Spencer, the United States Coast Survey and British Admiralty charts record submerged outlets from the gulf of Maine, the gulf of Saint Lawrence, and Hudson bay, respectively 2,664 feet, 3,666 feet, and 2,040 feet below sealevel.‡ The bed of the old Laurentian river from the outer boundary of the Fishing banks to the mouth of the Saguenay, a distance of more than 800 miles, is reached by soundings 1,878 to 1,104 feet in depth. Advancing inland, the sublime Saguenay fiord along an extent of about 50 miles ranges from 300 to 840 feet in depth below the sealevel, while in some places its borderings cliffs, 1 to 1½ miles apart, rise abruptly 1,500 feet above the water.

ARCTIC AMERICA AND GREENLAND

The islands of the Arctic archipelago are separated from each other by wide and deep valleys of subaerial erosion, and their shores, as well as that of Labrador and all the coastline of Greenland, west, east, and north, are cut by fiords mostly 1,000 to 1,500 feet deep. The maximum known sounding of these partly submerged valleys was reported by Koldewey in the Franz Josef fiord of eastern Greenland, where no bottom was found at 3,000 feet.

WESTERN EUROPE AND WESTERN AFRICA

The fiords and submerged valleys of the British isles and of Scandinavia show that the drift-bearing northwestern part of Europe stood in preglacial time 1,000

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*Am. Jour. Sci., third series, vol. xliii, pp. 389–402, May, 1892.

†A. Lindenkohl : Report of the U. S. Coast and Geodetic Survey for 1884, pp. 435–438 ; Am. Jour. Sci., third series, vol. xxix, pp. 475–480, June, 1885. James D. Dana, Am. Jour. Sci., third series, vol. xl, pp. 425–437, Dec., 1890, with an excellent map of the Hudson submerged valley and fiord.

‡Bull. Geol. Soc. Am., vol. i, 1890, pp. 65–70, with map of the preglacial Laurentian river (also in the Geol. Magazine, third decade, vol. vii, 1890, pp. 208–212).

to 4,000 feet higher than now. Southwestern Europe was then elevated, at least in part, to the very great altitude of nearly 9,000 feet above its present level, as is proved by the "Fosse de Cap Breton," the most remarkable and most fully surveyed submerged valley known. It reaches about 120 miles westward from the village of Cap Breton, near the mouth of the river Adour, of which it was a continuation. Many other valleys of similar character, but not traced to so profound depth, are also known on the western French, Spanish, and Portuguese coasts, and they have been recently well studied by Professor Edward Hull, who confidently ascribes their formation to a period of great epeirogenic uplift, attended in its culmination by the Ice age of northern Europe.*

Not only was a great part of Europe uplifted thousands of feet, but probably all the western side of Europe and Africa shared in this movement, of which we have the most convincing proof in the submerged channel of the Congo, about 400 miles south of the equator. From soundings for the selection of a route for a submarine cable to connect commercial stations on the African coast, Mr J. Y. Buchanan found this channel to extend 80 miles into the ocean, to a depth of more than 6,000 feet. The last twenty miles of the Congo have a depth from 900 to 1,450 feet. At the mouth of the river its width is 3 miles and its depth 2,000 feet. Thirty-five miles offshore the width of the submerged channel or canyon is 6 miles, with a depth of about 3,450 feet, its bottom being nearly 3,000 feet below the sea bed on each side. Another deep submarine valley, called the "Bottomless Pit," having soundings of 2,700 feet, is described by Buchanan on the African coast 350 miles north of the equator.†

Competence of the Preglacial epeirogenic Uplift to cause the Accumulation of the Ice-sheets

The coincidence of these great earth movements with glaciation naturally leads to the conviction that they were the direct and sufficient cause of the snowy climate forming the ice-sheets; and this conclusion is confirmed by the insufficiency and failure of the other theories which have been advanced to account for the Glacial period. In our Cordilleran belt, glaciers still remain on the higher ranges and peaks as far south as the general southern boundary of the old continental ice-sheet; and in Tuckerman's ravine on mount Washington the deeply drifted snow of winter usually lasts till August, spanning in a broad arch the brooklet of its melting. In Scotland, on the northern slopes and in the ravines of Ben Nevis and Ben Macdhui, many tracts of snow likewise linger until late in summer; and in Norway, as in Alaska, perpetual snow and icefields cover many square miles. No very great climatic change, probably not more lowering of the mean temperature than 10 or 15 degrees, such as must be produced by an epeirogenic elevation of 3,000 to 5,000 feet, would be sufficient to cause the storms of these north temperate regions to bring snowfall instead of rainfall upon the mountains throughout the year. Hence glaciation would gradually reach outward, with extension of the areas receiving snowfall at all seasons of the year, until ice-sheets enveloped vast plains of the uplifted continents, as in the upper part of the

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*The evidences of the preglacial uplift of Europe are the subject of a paper by the present writer in the Am. Geologist, vol. xxii, pp. 101-108, August, 1898.

†Scottish Geographic Magazine, vol.. iii, 1887, pp. 217-238

Mississippi basin, and on the present areas of the North and Baltic seas, northern Germany, and Russia.

Late Glacial or Champlain Depression known by fossiliferous marine Deposits overlying the Glacial Drift

NORTH AMERICA

Under their ice-burden, these continental areas finally were de pressed, in the later part of the Glacial period, until they mostly stood somewhat lower than now. The coastal submergence of New Hampshire and Maine ranged from 100 to 300 feet, as is known by fossiliferous marine beds there overlying the drift. In the Saint Lawrence valley the depression of the land below its present height, proved by the same kind of evidence, attained a maximum of at least 560 feet at Montreal, and it was about 400 feet in the northern part of the basin of lake Champlain; but it decreased southward, so that the Hudson valley and the basins of lake Ontario and the upper Laurentian lakes were above the sealevel. Around Hudson bay and southwestward to the area of the glacial lake Agassiz the epeirogenic downward movement of the ice-laden continent reached its limit mostly about 500 to 600 feet below the present elevation. All the area of the North American ice-sheet was similarly lowered from the great altitude to which it had been uplifted, so that in the late part called the Champlain epoch of the Glacial period the borders of the icefields were subjected to climatic conditions of warm and even hot summers nearly like those prevailing now in the same latitudes.

EUROPE

The Champlain depression of the British isles appears to have had a maximum of about 100 to 300 feet below the present sealevel in Lancashire and Scotland ; but marine shells glacially transported from early Pleistocene sea beds occur at much greater altitudes up to a maximum of 1,300 feet on Moel Tryfan, in northern Wales. The limit of the depression of Sweden and Norway was mostly between 100 and 600 feet; but its highest raised shoreline on the west side of the gulf of Bothnia exceeds 800 feet, and Baron De Geer computes the maximum subsidence of the interior of the peninsula as about 1,000 feet. All the glaciated area of Europe, like that of our own continent, sank in the Champlain epoch from the preglacial uplift to its present height, or lower, and has since been nearly unchanged in altitude or has experienced oscillations of moderate re-elevation.

Competence of the Champlain Depression to terminate the Ice Age

Although the adequacy of the preglacial epeirogenic uplift of this continent to produce its Pleistocene ice-sheet was tardily recognized and can not yet be said to be accepted by all American glacialists, it was distinctly claimed by Dana, in 1870, that the Champlain subsidence of the land beneath its ice-load, supposing it to have been previously at a high altitude, must have brought climatic conditions under which the ice would very rapidly disappear. This subsidence, however, probably affected the whole of the preglacially elevated areas, on each side of the North Alantic, before the growth of the ice-sheets was checked. For some time the increase in the ice accumulation may have exceeded the rate of depression, so that the surface of the thickening ice-sheets continued to hold an undiminished altitude. But at length the subsidence brought a warmer climate on the borders of the ice, causing it to retreat, and probably giving to it a mainly steeper frontal gradient than during its growth and culmination. To this steeper gradient and consequently more vigorous glacial currents I attribute the larger morainic accumulations of drift marking retreatal stages, both in North America and Europe, than on the outermost drift boundaries.

When the ice had considerably receded the outer portions of the depressed areas were somewhat uplifted to approximately their present height, which they have since held, excepting minor oscillations. Gradually as the ice-sheet of our continent withdrew from south to north a principally permanent wave of land elevation has followed, earliest uplifting the loess region of the Mississippi basin, later the areas of lake Agassiz, of the Laurentian lakes, including lake Champlain, and of the Saint Lawrence valley, and latest the country surrounding Hudson bay, where this movement is still in progress. The time since the departure of the ice there has been too short, as in Scandinavia, to allow the earth's crust yet to have completed its restoration to an isotatic condition.

Remarks upon Mr Upham's paper were made by Professor D. S. Martin and J. W. Spencer.

The next paper was entitled:

CLAYEY BANDS OF THE GLACIAL CUYAHOGA DELTA AT CLEVELAND, OHIO, COMPARED WITH THOSE AT TRENTON, NEW JERSEY

BY C. FREDERICK WRIGHT

The next two papers were read by title.

MIDDLE COAL MEASURES OF THE WESTERN INTERIOR COAL FIELDS

BY H. FOSTER BAIN AND A. G. LEONARD

[*Abstract*]

The most important coalfield west of the Mississippi, so far as present development is concerned, is that which stretches from north-central Iowa across portions of Missouri, Nebraska, Kansas, Arkansas, Indian Territory, and into Texas. In recent years there has been a good deal of geological work done within this field, and some of the older conceptions of its stratigraphy are being changed. It is proposed to discuss here certain problems relating especially to the northern end of the field, that portion extending from central Iowa to southwestern Kansas.

The change from the condition obtaining in the early Des Moines to those present when the Missourian began was a gradual one. During the former period there was no uniformity anywhere and the field was broken up into a multitude of minor basins of deposition, each the theater of an individual sequence of events, while during the latter the whole of southwestern Iowa, northwestern Missouri, eastern Kansas, and probably an even larger area acted as a unit. The turbulent conditions of the earlier period became merged into the uniform conditions of the later one. Gradually larger and larger areas came to act together and local sequences became of wider and wider applicability. It is the beds of this inter-

mediate period which were recognized as the Middle Coal Measures, and, in the absence of unconformity, it will be seen that there is *a priori* reason to expect a series of beds intermediate in character and position between the typical Des Moines and the recognized base of the Missourian. All who have written on the subject have recognized that the Coal Measures mark a continuous sequence of deposition with only local breaks. Any divisions must be more or less arbitrarily established, though they may be none the less useful.

The Des Moines beds, in the central portion of Iowa, consist of a thick mass of shales and sandstones, showing no definite order of arrangement which may be recognized over any considerable area, covered by a more regular sequence of which the upper portion may be recognized over a considerable area; but as one travels south two changes take place: (1) the upper member of the latter section thickens from barely 30 feet on the South Raccoon to over 70 feet on Middle river near Winterset; (2) the various members of the section thin out, and are replaced until in the southeastern portion of Madison county none of them can be made out.

South from here in Clark and Lucas counties the work has not yet been carried on in sufficient detail to allow a general section to be made out. It is, however, known that there are in the region strata of the same general type as those found in Madison, Dallas, and Guthrie counties, though probably detailed correlation will be impossible.

Along the southern border of the state the Des Moines beds outcrop from the Mississippi river west to Decatur county, where they become buried beneath the Bethany. As far west as the Chariton river the beds may be referred unhesitatingly to the lower division, corresponding with the Cherokee shales of Kansas. Their character is shown in exposures and mine sections along the Chicago, Milwaukee and Saint Paul railway from Ottumwa southwest.* Above these is a formation, including several limestone beds and one widely worked seam of coal, which has been called the Appanoose formation.† In general character these strata correspond to those seen farther north at the same horizon.

As has been pointed out by Keyes,‡ there is a close correspondence between the sections made out in Iowa, Missouri, and Kansas. These may be summarized as below:

	Iowa.	Missouri.	Kansas.
3	No name	Pleasanton	Pleasanton.
2	Appanoose	Henrietta	Pawnee. Oswego.
1	Cherokee	Cherokee	Cherokee.

The Middle Coal Measures as originally defined included the two upper divisions noted here. Swallow § recognized along the Missouri and at the top of his section some 30 feet of sandy shales. White and St John found about the same thickness along the Raccoon river. Between these two points it is now known that the sandy member attains a considerable thickness and becomes sufficiently distinct to war-

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* Iowa Geological Survey, vol. v, plate xiv.

† Iowa Geological Survey, vol. v, pp. 378, 394.

‡ Proceedings Iowa Academy of Science, vol. iv, pp. 22–25, 1897.

§ Geological Survey of Missouri, vols. i and ii, 1855, pp. 82, 83.

rant giving it a separate designation. For this division Haworth's term Pleasanton * seems to have precedence.

For the middle member there is no good term, though Henrietta has been used in the general sense here suggested; † but if this usage is to be adopted, it would seem desirable that the formation be properly defined and some general section of it as typically exposed be given. Since, however, Henrietta was first applied to a distinctive phase of the formation, that displayed in southwestern Missouri, it will probably be found better in the end to adopt a general term for the whole region, retaining the terms now in use, Pawnee, Oswego, Henrietta, Appanoose, and Raccoon River beds, for local use. This is the more advisable, since, while the beds show certain general characters common to all and are probably of essentially contemporaneous origin, they really contain the record of deposition in four and perhaps more essentially distinct though minor geological provinces.

This paper is printed in full in the Journal of Geology, vol vi, pages 577–588.

THE PRINCIPAL MISSOURIAN SECTION

BY CHARLES R. KEYES

The following paper was read by the author:

TOURMALINE AND TOURMALINE SCHISTS FROM BELCHER HILL, COLORADO

BY HORACE B. PATTON

Remarks were made by Vice-President Emerson. The paper is printed in this volume.

The Society adjourned at 1 o'clock p m for the noon recess, and reconvened at 2 o'clock. The first paper of the afternoon was entitled

NOTE ON A METHOD OF STREAM CAPTURE

BY ALFRED C. LANE

I do not know whether it was the result of my instruction or of my own misconceptions that I used to conceive of stream capture as culminating in a somewhat sudden diversion of the captured stream, perhaps in time of flood, into the channel of the conquering stream. Such terms as "piracy" carry with them, perhaps unintentionally, the thought of violent and sudden action.

In any case the method of rearrangement of drainage which I shall attempt to describe struck me as a novelty when I first came upon it in operation. In this process the valley of the weaker stream is drained by subsurface drainage until the valley becomes a dry valley, except in times of rain. As soon as the channel is verdure clad, erosion practically ceases and the valley level remains stationary, or may even rise through loam washed down from the side, until some stream

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* Kansas University Quarterly, vol. ii, p. 274, 1895.

† Keyes: Proceedings Iowa Academy of Science, vol. iv, p. 23, and Engineering and Mining Journal, February 26, 1898, p. 254.

working backwards or sideways through the divide succeeds in reoccupying it. In such case it would be more appropriate to speak of the former stream as dying and being succeeded by the latter, rather than to speak of one stream capturing another.

We ought to keep clearly in mind in considering the phenomena of the case the fact that the visible rivers and streams which are actively engaged in the work of surface erosion represent but a remnant or residuum of the rainfall after a part has been evaporated and a large part has passed beneath the surface of the ground to find its way in subterranean channels.

In Michigan, where there is a rainfall of about 3 feet, not more than a foot can be accounted for in the surface runoff. Hence it is that an increase in rainfall causes the visible runoff to increase much more rapidly, while this visible runoff may disappear entirely when the rainfall becomes only low. According as the stream bed strata are more or less extensively porous will the visible runoff be more or less conspicuous. Thus I have often observed streams appear in considerable volume where they had cut down to or nearly to impervious bed rock, which above and again below that point were lost in the sands and gravels of their own courses, and utterly inefficient in erosive action.

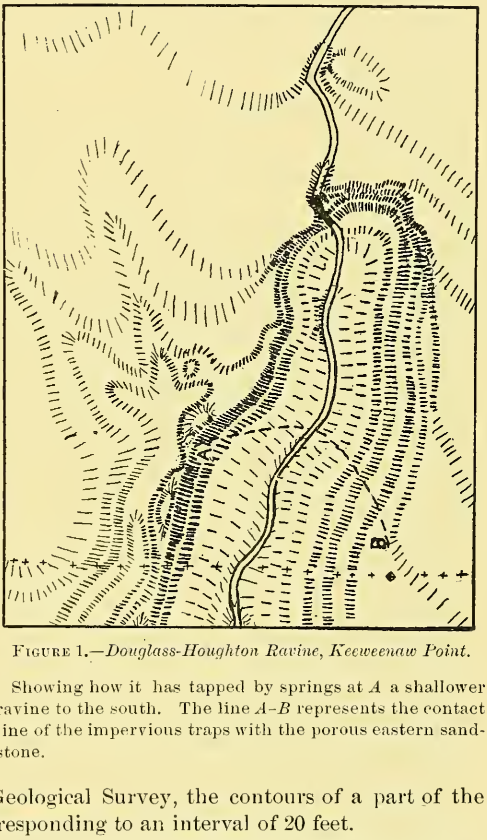

Figure 1.—*Douglass-Houghton Ravine, Keeweenaw Point.*

Showing how it has tapped by springs at *A* a shallower ravine to the south. The line *A–B* represents the contact line of the impervious traps with the porous eastern sandstone.

The first time that I saw the connection between subsurface drainage and stream or valley capture was in a stream similarly situated to the Douglass-Houghton, and as the same phenomena are more likely to be visited and studied there by the geologist since it is classical for other reasons, I will use it as an illustration. Figure 1 shows in a sketchy way, with the help of Bulletin 23 of the United States Geological Survey, the contours of a part of the stream, each row of hachures corresponding to an interval of 20 feet.

The Douglass-Houghton comes down the trap range in a shallow, relatively broad valley which has cut in but 10 to 20 feet. Just before reaching the edge of the trap range, which at this point has overridden the "eastern sandstone," which elsewhere is deposited unconformably on it,* it plunges by a picturesque waterfall into

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* See vol. vi, part ii, Geological Survey of Michigan, by L. L. Hubbard. In press.

a narrow gorge over 100 feet deep. Just to the south of it runs another gully not very much shallower while on the trap range than the Douglass-Houghton, though it has less water and smaller drainage area. Below the falls it comes quite close to the Douglass-Houghton ravine, as the figure shows, and at a point, *A*, on the side of the deep ravine corresponding to the bottom of the shallower, we find springs where the two enter the porous sandstone. In other words, the bottom of the upper valley becomes leaky and has let out the water into the lower. The shallow ravine swings away again from the Douglass-Houghton and grows deeper, but does not carry water in ordinary weather, and erosion in it must be very slow. The point where the springs occur is liable to landslips. Several have occurred since I first saw the place, nearly ten years ago. The softening action of the water renders them especially frequent, and in this particular place the work of geologists anxious to study the contact may have accelerated matters, so that I should not be surprised to see the day when the southern gully will appear a direct tributary of the main ravine.

Though the action above described might more properly be designated valley capture than river capture, I have no quarrel with nomenclature, but wish to call attention to the probability that in many cases there is an intermediate stage in which a valley is undrained and generally dry for a time between its transference from one stream to another. This is the more likely to be true the more porous the valley bottom is. This remark suggests one case of especial interest where this method of rearrangement of the drainage occurs. The streams draining the ice front carried away vast quantities of sand and gravel to be deposited in their valleys; hence in them the amount of porous subsurface drainage through the porous beds of the valley is likely to be very large. The contribution of water from the melting ice has been abstracted, and hence such old channels are now occupied by streams much too small for them. At times the amount of surface drainage is so slight that there are merely swamps or here and there pools and lakes in the sand plains, with no apparent outlet, in spots where here and there the subsurface current comes to the daylight. Such lakes are typically known as "crooked lakes" in our Michigan nomenclature. The above state of affairs I suppose to be widely prevalent. In Michigan, over the lower peninsula, it is also true that the ice retired first from the higher parts of the rock surface and extended in three lobes with two cusps between. The three lobes occupied lake Michigan, lake Huron, and Saginaw bay. Streams like the Tittabawassee, the headwaters of the Cass, and Huron rivers, and Dowagiac creek are, as Doctor Gordon has remarked, especially liable to the kind of capture that I have described from a host of vigorous streams which work up directly from the lake and have only to cut through intervening unconsolidated moraines, which often seem to have overriden gravels connected with the gravels of these glacial drainage valleys. When they get fairly gnawing at the moraine numerous springs appear about their headwaters, and they are helped by flowing wells put down by farmers. By the time they have got into the old drainage valley, considerably before they have abolished the divide between them and the old glacial channel, the subsurface drainage into them is so ample that the old valley is so dry as to be overgrown with verdure. An excellent cross-section may be studied at Rose City (township 24 north, range 3 east). At Rose City itself we are near the headwaters of a stream which flows fairly direct to lake Huron. The region is full of springs and of artesian wells which have 10 to 20 feet head. Go about two miles west, passing over two moraine lines already dissected by transverse valleys, and you overlook an old sandy continuous valley between two moraine lines, now entirely dry, which once drained past West Branch, and, after stopping a while in lake Saginaw (Taylor), passed down the Grand River valley to lake Michigan and the Mississippi.

The second paper of the afternoon was as follows:

VOLUME RELATIONS OF ORIGINAL AND SECONDARY MINERALS IN ROCKS

BY CHARLES R. VAN HISE

Remarks were made by Professor Emerson.

The following paper was then read:

MAGMATIC DIFFERENTIATION IN ROCKS OF THE COPPER-BEARING SERIES

BY ALFRED C. LANE

[*Abstract*]

In certain of the effusive sheets which so largely make up the Lower Keweenawan or Copper-bearing series a difference may be noted between the upper and the lower part of one bed or flow other than the difference between the amygdaloid and compact melaphyre. At the top amygdaloid, somewhere about a third of the way below the top of the bed, the rock is like Pumpelly's "ash-bed diabase" type—felsitic, grayish green, with a conchoidal fracture, and conspicuously porphyritic feldspar. Somewhat above the bottom the rock is of the type of Pumpelly's "luster-mottled" type—heavier, darker, not so brittle, showing laths of feldspar embedded in augite patches—that is, ophitic. I have called these two varieties of melaphyre porphyrite and ophite respectively. There is more augite in the latter type, and observations after Michel-Lévy's method on doubly twinned (albite-Karlsbad) sections* of feldspar show a steady, perhaps continuous, variation from Ab_2An_1 to Ab_2An_3.

Analyses A 1 and B 1 are respectively from near the bottom and top of one sheet, A 2 and B 2 from the bottom and middle of another. The silica remains fairly constant, while CaO replaces Na_2O toward the bottom. The increase in amount of augite (from 15 to 27 per cent)* and in the basicity of the feldspar is balanced by decrease in amount of olivine (from 17 to 6 per cent).* Toward the top the reddish micaceous pseudomorphs of this latter mineral are conspicuous, while in the ophite it is represented only by small corroded granules, crowded in between the augite patches. The estimate of the percentage of constituent minerals originally present in analyses A 1 and B 1 † seems to show that the amount of feldspar remains nearly constant (52 to 55 per cent), so that, as the thin sections indicate, the augite is built at the expense of the olivine. The porphyritic olivine and oligoclase of the

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*Geological Survey of Michigan, vol. vi, pt. i, plate v, and chapter vi. In press. By the kindness of the state geologist, Mr L. L. Hubbard, I am permitted to refer to this report, which contains much detail in connection with this paper, a little in advance of publication. The part referred to is all printed.

†Loc. cit., pp. 146, 147.

top, which are often clotted together, were largely formed before the lava came to rest. Apparently the early formed oligoclase rose to the top and a sodiferous magma was thus formed, which had not so corrosive action on the olivine as the calcareous magma left below.

We find the same kind of relation that exists between the top and bottom of the same flow on comparison of different flows. This would suggest that a similar differentiation went on before eruption; but among the set of dikes which are by all authorities supposed to be feeders to this same set of flows we find a variation (C 1 and D 1) like that described by Lawson and Shutt between the center (D 2 and D 3) and margin (C 2 and C 3) of dikes of the same family on the north shore of lake Superior. Indications of analogous variation may be found elsewhere (D 4 and C 4). In these analyses the decrease of lime is concomitant not only with the increase of alkalies, which is characteristic in both variations, but with an increase of silica. Lawson ascribes this difference to a concentration of the water glass soluble in superheated water toward the last solidified center.*

This explanation seems reasonable, and in that case it is natural that the differentiation in effusives should go another gait, for the SiO_2 is no longer highly soluble, but quite the contrary. We might by analogy suppose that the differentiation of the calcareous magma of the ophite which (as the ophitic texture shows must be formed in a state of rest) is almost surely the last to solidify, is due to a concentration of the more fusible (soluble in caloric) part. Augite is much more fusible than olivine, and labradorite is probably the most fusible of the plagioclase series. It is worth noting, too, that this effusive differentiation tends toward Bunsen's normal basaltic magma (A 3).

GROUP A—*Effusives* (*lower Part of Flow*).

Components.	1	2	3
SiO_2	46.13	46.32	48.47
TiO_2	....	2.78	
Al_2O_3	19.79	15.95	30.16
Fe_2O_3	7.24	0.86	
FeO	3.79	8.92	
MgO	7.27	4.08	6.89
CaO	11.43	10.23	11.87
Na_2O	2.55	3.56	1.96
K_2O	0.52	1.23	0.65
H_2O	1.83	3.25	....
	CO_2 0.29	MnO 0.89	....
Sum	100.84	....	....
Sp. Wt.	2.877	....	....

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* See Becker on Fractional Crystallization, in Am. Jour. Sci., fourth series, 1897, vol. iii, p. 21. I cannot understand why Becker should consider fractional crystallization antipodal to magmatic differentiation, for it seems to me a most effective way of promoting it. However, it is only a question of names.

Group B—*Effusives* (*upper Part of Flow*).

Components.	1	2
SiO_2	46.45	49.20
TiO_2	......	2.26
Al_2O_3	16.60	16.00
Fe_2O_3	2.72	3.03
FeO	7.25	7.10
MgO	9.21	6.98
CaO	6.32	3.44
Na_2O	4.05	5.05
K_2O	1.02	1.31
H_2O	5.01	4.51
	Co_2 0.40	MnO 1.17
Sum	99.03	......
Sp. Wt.	2.781	......

Group C—*Normal basic Intrusives.*

Components.	1	2	3	4
SiO_2	47.99	47.83	47.50	45.73
TiO_2	2.71	......	......	......
Al_2O_3	16.57	*30.28	*22.44	13.48
Fe_2O_3	6.01	4.57	7.40	11.60
FeO	5.13			
MgO	6.01	*4.32	*3.71	15.40
CaO	9.36	6.72	10.21	9.92
Na_2O	2.00	1.30	1.62	3.24
K_2O	1.39	Tr.	1.29	0.47
H_2O	2.64	2.05*e*	2.85*	0.94
P_2O_5	......	2.19	0.34	......
Sum	*99.90	92.26	97.36	100.78

Group D—*Quartziferous basic Intrusives* (*central*).

Components.	1	2	3	4
SiO_2	54.11	57.50	52.47	52.06
TiO_2	0.85	......	......	......
Al_2O_3	12.09	*23.44	*25.54	13.67
Fe_2O_3	4.00	5.07	6.31	15.97
FeO	11.51			
MgO	3.47	*2.76	*2.31	5.01
CaO	6.72	5.62	6.62	8.15
Na_2O	2.73	2.01	3.23	3.36
K_2O	1.49	0.45	0.54	0.86
H_2O	1.39	2.25*e*	1.28*e*	1.05
P_2O_5	0.12	2.02	1.16	......
Sum	99.23	101.12	99.46	100.13

* Loss on ignition.

The analyses are all, except C 4, D 4, A 3, cited from volume vi, Geological Survey of Michigan, pages 215 and 266, where the original references and descriptions and other pertinent analyses may be found.

C 4 and D 4 are from the American Geologist, volume xxii (1898), page 87, by T. L. Watson. Bunsen's normal basalt analysis, A 3, is in many text books. I cite from Neumayr's Erd-Geschichte.

Comparable analyses in A and B, C and D have the same number, and though the figures marked with a star are certainly erroneous, the rocks (as the water or loss shows) none too fresh, and the accuracy of the analyses generally none too high, yet as the corresponding analyses of each set are by the same chemist, and four different chemists represented, I think the inferences I have drawn, confirmed as they are by petrography, are fairly safe. Other recent analyses of plutonic rocks of the same family may be found in the Journal of Geology, volume i (1893), page 712, and volume vi (1898), page 387.

The full paper is printed in volume vi of the reports of the Michigan Geological Survey.

The next paper was entitled:

DEVELOPMENT OF THE OHIO RIVER

BY WILLIAM G. TIGHT

Remarks were made by I. C. White and G. F. Wright.

The next two papers were read by title.

CLASSIFICATION OF COASTAL FORMS

BY F. P GULLIVER

[*Abstract*]

This paper proposed a scheme for the classifications of the various forms of the coasts according to their origin and stage of development. Two markedly differing classes of initial forms were pointed out, those following elevation and those following depression of the land. Each class was shown to have characteristic forms at various stages of development, and the writer urged others to think of all the forms on the coast or along the shore as in a certain stage of their life history. Thus it will be possible to conceive more easily the form from which any given example has come and toward what form it is developing.

The paper was discussed by W J McGee and others, who emphasized the value of genetic classifications such as had been made in the above paper.

This paper is published in full in the Proceedings of the American Academy of Arts and Sciences, volume xxxiii, 1898.

DISSECTION OF THE URAL MOUNTAINS

BY F. P. GULLIVER

The paper is printed in this volume.

The next paper was read by the author:

NOTE ON MONADNOCK

BY F. P. GULLIVER

[*Abstract*]

A recent trip to this region in southern New Hampshire was described and the relation of the more resistant rock of which this mountain is composed to the New England upland, spread out as a great carpet at its feet, was strongly emphasized. The dissection of the old peneplain since its uplift was considered and two well marked former stream grades were shown to exist in this region. The correlation of these old grade-plains way above the present sphere of stream action with those previously observed and reported to the Society by the same writer was left until more fieldwork had been done.

Remarks were made by Professor Emerson.

The following was read by title:

SPACING OF RIVERS WITH REFERENCE TO THE HYPOTHESIS OF BASELEVELING

BY N. S. SHALER

In the absence of the author, the last paper of the program was read by Professor Ellen Hayes, of Wellesly College.

THE CONTINENTAL DIVIDE IN NICARAGUA

BY C. WILLARD HAYES

The meeting was declared adjourned.

Register of the Boston Meeting, 1898

S. P. Baldwin.
G. H. Barton.
Florence Bascom.
S. Calvin.
W. B Clark.
W. O. Crosby.
R. E. Dodge.
C. R. Eastman.
B. K. Emerson.
H. L. Fairchild.
A. C. Gill.
F. P. Gulliver.
Arnold Hague.
Arthur Hollick.
T. C. Hopkins.
E. O. Hovey.
H. C. Hovey.
E. E. Howell.
Alpheus Hyatt.
J. P. Iddings.
R. T. Jackson.
A. C. Lane.
T. H. McBride.
A. M. Miller.
T. F. Moses.
W. H. Niles.
H. B. Patton.
W. H. Pettee.
H. F. Reid.
W. N. Rice.
J. C. Smock.
J. W. Spencer.
W. G. Tight.
Warren Upham.
C. R. Van Hise.
L. G. Westgate.
I. C. White.
H. S. Williams.
J. E. Wolff.
A. A. Wright.
G. F. Wright.

Total registration, 41.

The following Fellows, not present during the sessions of the Society, were present at the sessions of the American Association for the Advancement of Science:

A. S. Bickmore.
R. T. Hill.
W J McGee.
F. J. H. Merrill.
N. S. Shaler.
R. S. Woodward.

Total attendance, 47.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 10, PP. 21-26, PLS. 1-2 JANUARY 31, 1899

TOURMALINE AND TOURMALINE SCHISTS FROM BELCHER HILL, COLORADO

BY HORACE B. PATTON

(*Read before the Society August 23, 1898*)

CONTENTS

INTRODUCTION

Tourmaline is a not uncommon mineral in the northern part of Jefferson county, Colorado. It is to be found as an ingredient of the quartz-feldspar boulders which strew the mesas bordering the foothills west of Denver and in the beds of the streams which drain the crystalline schists of these foothills. It may also be found in place in the numerous pegmatite veins that everywhere cut the schists. Beautiful lustrous black crystals, often two or more inches in diameter, have been obtained from these pegmatite veins. In rare cases colors other than black may be seen, as for instance, some small crystals, about a quarter of an inch in diameter, with white centers and black margins, found in a pegmatite boulder near Golden.

While the pegmatite veins may well be considered the habitat of the Jefferson County tourmalines, in some cases this mineral occurs with somewhat different association. On the so called Belcher Hill road, one of the roads leading from Golden to Central City, are several unusually interesting occurrences of tourmaline.

This road runs north from Golden, skirting the foothills for a distance of some five or six miles, and then turns westward and climbs the hills in sharp zigzags until an altitude of 1,000 feet above the base is reached.

At the summit the country flattens out and the first mountain ranches begin to appear. On the way up the mountain the country rock is well exposed along the road. It consists of micaceous schists of greatly varying degrees of schistosity. Not infrequently they become extremely micaceous and are then beautifully crinkled. The schists are composed of both white and black mica associated with quartz, and sometimes, but not characteristically, with feldspar. One may see at frequent intervals during the ascent numerous veins of quartz or of quartz and feldspar containing the habitual black tourmaline. More extensive exposures, however, occur just before reaching the summit of the long climb opposite the first piece of cleared land to be seen on the right of the road. There are, in fact, three outcrops, to which attention may be specially directed, differing from each other and from most of the tourmaline occurrences of this region. They will be described separately.

First Locality: Tourmaline as a Vein Mineral

An 18-inch vein of quartz and tourmaline is to be seen striking almost at right angles to the road and exposed in the roadway. The vein is not quite parallel to the cleavage direction of the mica-schists which strike east and west and dip nearly vertically. The tourmaline at this locality is a fine grained schorl-like mass more or less banded with white vein quartz. The vein may be traced for two or three hundred feet in the field to the northeast by means of fragments on the surface. Numerous blocks of this rock lie scattered along the road for 50 or 100 feet below the outcrop.

In most cases tourmaline predominates over quartz. It does not, as is usually the case, occur in coarse grains or crystals, but rather in a dense felted mass, the fibrous character of which is evident only upon a close examination, as the fibers or needles are hardly over one millimeter in length. The banded structure of the rock is usually very marked, and the strong contrast between the white of the quartz and the black of the tourmaline is very striking. Where quartz grains are intimately mixed with tourmaline, as is not infrequently the case, this banding becomes less pronounced or entirely disappears.

A thin-section of this rock discloses under the microscope granular quartz, sometimes distinct prisms and sometimes irregular grains of tourmaline, together with a very little muscovite. In addition to these minerals may be mentioned a few small, irregular grains that show very high refractive powers and may well be considered rutile. The tourmaline is very strongly characterized under the microscope. It shows strong negative birefraction; also a rather high index of refraction and very striking pleochroism. In moderately thin sections the ordinary ray is almost completely absorbed and shows a dull blackish green color, while the extraordinary ray is light brown.

The effect, if any, of this vein on the adjacent schist could not be observed at the place of outcrop, but to the west of the road lie blocks of schist which show a partial impregnation by tourmaline, and also a gradual disappearing of the tourmaline in the direction of the cleavage plane. Judging from the occurrence of tourmaline at the two other localities described below, it is probable that these loose blocks came from close contact with the quartz-tourmaline vein.

SECOND LOCALITY: TOURMALINE IMPREGNATING SCHIST AT CONTACT WITH A LARGE PEGMATITE VEIN

This is to be found about 500 feet up the road—that is, to the westward of the first locality. The outcrop is more extensive than at the first named locality. It consists of a pegmatite vein about 10 feet wide where it crosses the road, cutting the road diagonally with a northeast-southwest strike. The tourmaline, which is to be found only sparingly in the vein itself, occurs impregnating the schists at contact with the vein. Just at the fence the contact may be seen well exposed. The impregnation extends about two to three feet from the line of contact, and the black streaks of tourmaline are usually parallel with the schist cleavage. To the southwest of the road the pegmatite vein takes a nearly north-and-south course, and continues about 10 feet wide for 200 or 300 feet, and then gradually widens to about double this width. On both sides of the vein the schists are thoroughly metamorphosed for a foot or two from the contact. They lose in places all traces of the original cleavage, and develop into aggregates of quartz and tourmaline to the entire exclusion of the mica. Where this alteration is most complete the streaks of tourmaline do not appear to bear any relationship to the original cleavage direction. Curiously enough, as the vein widens the tourmalinizing of the schist becomes less and less marked, till it ceases altogether where the vein ends suddenly at its widest point.

Fragments of this tourmalinized schist are thickly strewn along both sides of the road, and the varying structures may be well studied from these fragments. In general, the rock may be said to present the appearance of a laminated or banded grayish or reddish gneiss, and without close observation one would hardly suspect the presence of tourmaline. Usually the banded schistose structure is sharply defined and the bands straight and parallel, but not infrequently a decided crinkling of the bands is to be observed similar to that noticed in the neighboring mica-schists. The bands vary in thickness, but are usually very thin, in some cases not over one millimeter thick.

This rock consists of quartz, tourmaline, and muscovite. Biotite, although very abundant in the immediately adjacent mica-schist, is usually entirely wanting in the tourmaline-schist. The tourmaline has evidently been formed at the expense of the biotite. The grayish or reddish portions are composed of quartz or of quartz and muscovite. Feldspar appears to be entirely lacking. In many cases the main portion of the rock is composed of a mass of quartz, with or without muscovite, through which run thin black lines of tourmaline. In still other cases the quartz-muscovite mass is penetrated in two different directions by parallel lines of tourmaline. These two series of black lines are sometimes almost at right angles to each other; at other times they make sharply oblique angles. By their intersection with each other they thus produce a beautiful reticulated structure. A still different structure is produced when one set of these lines is sharp and straight while the other is broad and wavy or crinkled.

This tourmalinized schist is cut by numerous small sharp veins of quartz or of quartz and muscovite. These vary from a line to several inches in thickness. They sometimes are parallel, but often cross each other. These cutting veins not infrequently have affected the process of tourmalinization, inasmuch as a more intense tourmalinization is to be noticed in the immediate vicinity of the veins. Where much muscovite is present in the veins this effect appears to be less marked. Coarser crystals of tourmaline may also be seen in these narrow veins, or they may project slightly into the quartz mass of the vein.

Under the microscope the tourmaline of this locality is seen to be very similar to that of the first described locality. Usually the grains are irregular in outline, or even very ragged, and then filled with quartz inclusions. Frequently, too, there occur small darker colored pleochroic zones surrounding yellowish specks of either rutile or zircon or of some similar mineral. Occasionally the tourmaline shows well defined prismatic habit with rhombohedral terminations.

In addition to the above mentioned minerals, there also occurs a very little muscovite in the sections studied. This scarcity of muscovite, however, is only accidental, as it is very abundant in most of the hand specimens. In addition may be mentioned a few small grains of a white mineral with weak birefraction and strong index of refraction. They are taken to be apatite.

Photographic reproductions of these structures, as shown in figures 1 and 2, plate 1, and in figures 1 and 2, plate 2 (about one-half natural size) give but a faint idea of the delicacy of the lines and of the beauty of the original specimens, but they may serve to show the variety of the

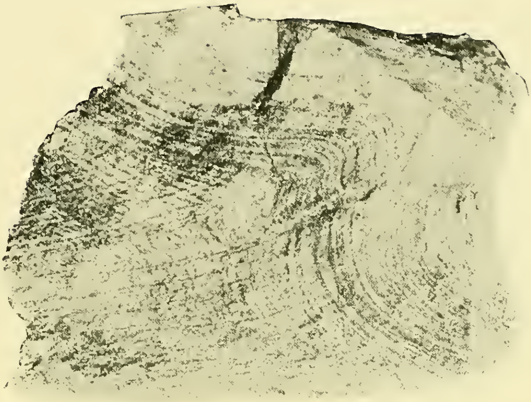

FIGURE 1—TOURMALINE SCHIST

From second locality, Belcher Hill, Colorado

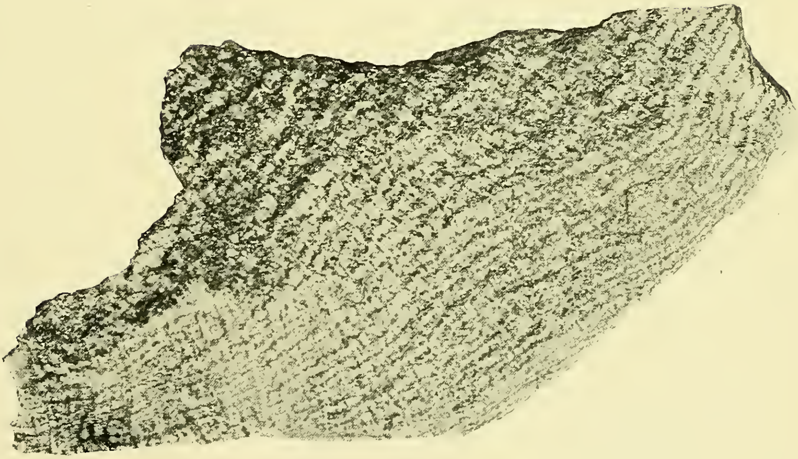

FIGURE 2—TOURMALINE SCHIST

From second locality, Belcher Hill, Colorado

TOURMALINE SCHISTS

FIGURE 1—TOURMALINE SCHIST

From second locality, Belcher Hill, Colorado

FIGURE 2—TOURMALINE SCHIST

From second locality, Belcher Hill, Colorado

TOURMALINE SCHISTS

structures involved. All the dark colored lines in these reproductions represent tourmaline, while the light colored portions are mostly quartz. In figure 1, plate 1, and in figure 2, plate 2 may be seen the cross-hatched structure produced by narrow streaks of tourmaline crossing each other.

Third Locality: Tourmaline impregnating Schist at Contact with small Pegmatite Veins

Some 1,500 feet farther along the road beyond the first locality, just where one first comes in sight of the "Rocky Mountain ranch," occurs a vein of pegmatite about two to three feet in width. This vein runs straight up and down the hill at right angles to the road. It divides into branches which enclose "horses" of schist. The cleavage of the schist and the vein strike in the same direction. Here, too, the schist, which is very micaceous, is impregnated with tourmaline on both sides of the pegmatite vein, as are also the enclosed horses. The streaks of tourmaline run parallel to the vein and to the rock cleavage. The vein may be traced about 200 feet down the hill. Farther down are other veins of pegmatite, striking in the same direction and accompanied by similar alteration of the schist at contact.

At this locality the country rock has not been extremely altered at contact with the pegmatite veins, and the rock cleavage has not been apparently lessened. The schist here is a friable, soft mica-schist of a beautiful bronze-like luster. Near the contact it contains minute, delicate prisms and needles of black tourmaline scattered thickly but very irregularly throughout the mass. In places this tourmalinized rock has a well defined crinkled structure.

Under the microscope the tourmaline is seen to be in sharply defined prisms which often show double termination, one end having a very flat rhombohedron and the other end a less flat rhombohedron. Light yellow to blood red stains of iron oxide abound and explain the bronze-like luster of the rock. Quartz is not very abundant and the biotite is present only in traces.

Discussion as to Origin of these Tourmaline Rocks

As to the origin of these tourmaline rocks it is evident that at the last two localities they are local modifications of the mica-schists which form the country rock, and are limited to a narrow zone of contact with veins of pegmatite. In all three localities, and this applies to all occurrences of tourmaline seen by the author in this region, the tourmaline occurs only in or near veins. This mineral does not appear to form an important constituent of the surrounding schists. In a few cases, however, the country rock appeared to carry a little tourmaline, together with a large amount of biotite.

Of course, this quite agrees with what is generally known about the occurrence of tourmaline. Only a few instances are given, as far as the author is aware, where tourmaline occurs as one of the main ingredients in a schistose rock, without any connection with fissures. Such rocks, for instance, are mentioned by Zirkel as occurring in the Erzgebirge of Saxony.* Usually tourmaline is found near the margin of granite masses, or in the rocks adjacent to large masses of granite, and in either case are considered to be contact features of the granite.

A case in point, which is similar in some respects to the one under discussion, is the occurrence of tourmaline at Auerberg, in Saxony.† At this locality there is a vein of quartz and tourmaline cutting through a mass of mica-andalusite-hornfels near the junction with the granite. The hornfels, itself a slate rock metamorphosed by contact with granite, has been tourmalinized on both sides of the vein, the tourmaline taking the place of biotite and andalusite.

Many other cases might be quoted where tourmaline occurs in connection with fissures at or near the junction with granite. Apparently, however, there is no true granite in this region; at least there is no large mass of granite capable of producing ordinary granitic contact phenomena. The pegmatite veins of these foothills are usually composed of coarse granular aggregates of reddish microcline and quartz, with or without muscovite, and occasionally garnet. They frequently resemble segregation veins in that they shade off into the adjoining schists without any well defined vein wall. One of the veins on Belcher hill broadens out to a considerable width, but is not as large as many of the pegmatite veins of this region. It may be an intrusive dike, but in the opinion of the writer these and other pegmatite veins of the region are not of such origin. Without entering into the discussion of the origin of the pegmatite veins, the following points may be emphasized in conclusion:

SUMMARY

The tourmaline on Belcher hill occurs—

1. In separate crystals in pegmatite veins.
2. In black schorl-like masses with quartz, filling fissures in the crystalline schists.
3. In mica-schists, at the junction of veins of pegmatite or of quartz, in the form of finely disseminated grains and needles replacing biotite and sometimes feldspar and even quartz.

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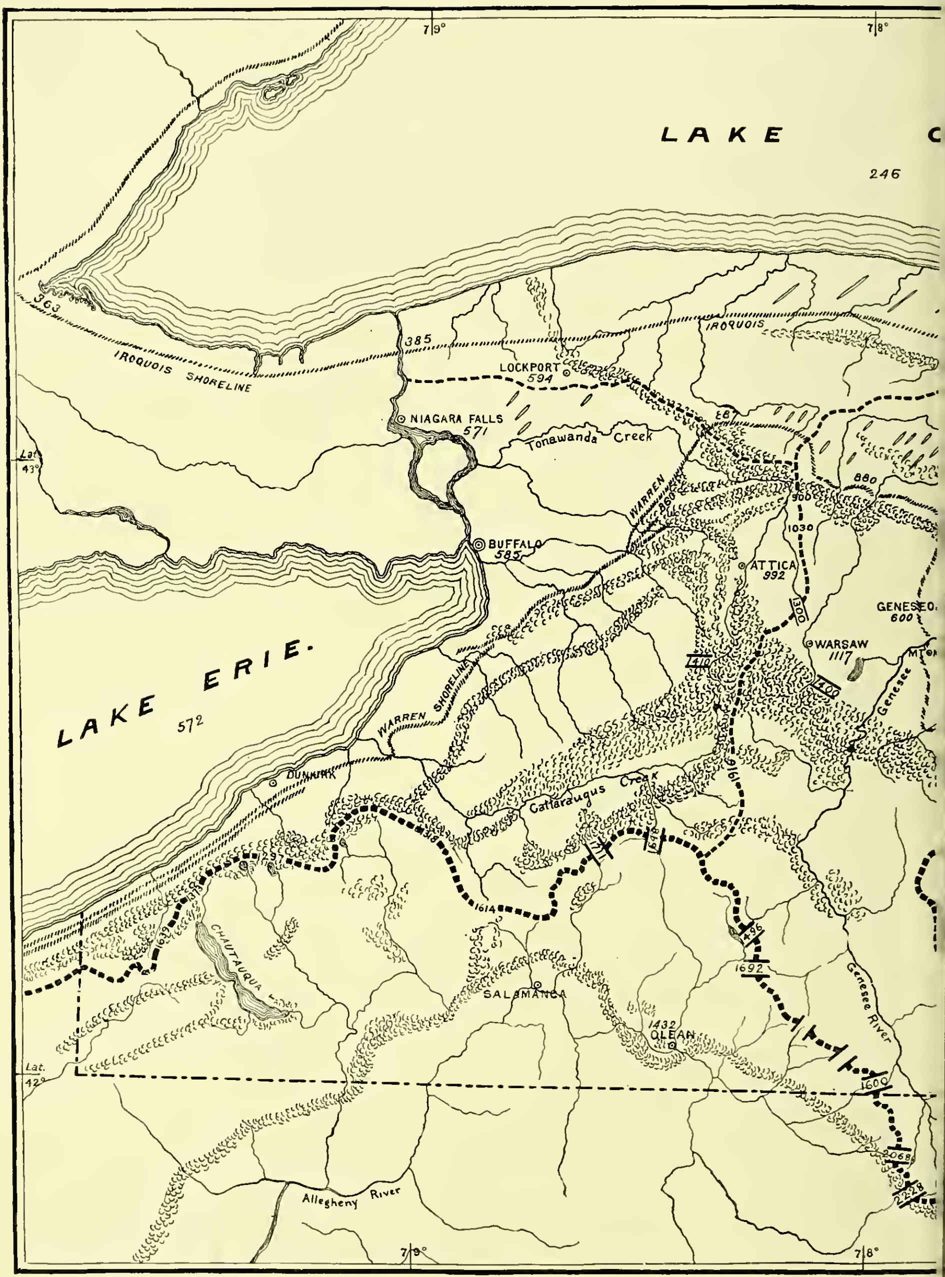
* Zirkel: Lehrbuch der Petrographie, vol. 3, p. 410. Leipsic, 1894.

† Zirkel: Lehrbuch der Petrographie, vol. 2, p. 119.



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Parallel bars indicate
Numerals show altitu
Drumlins are indicat
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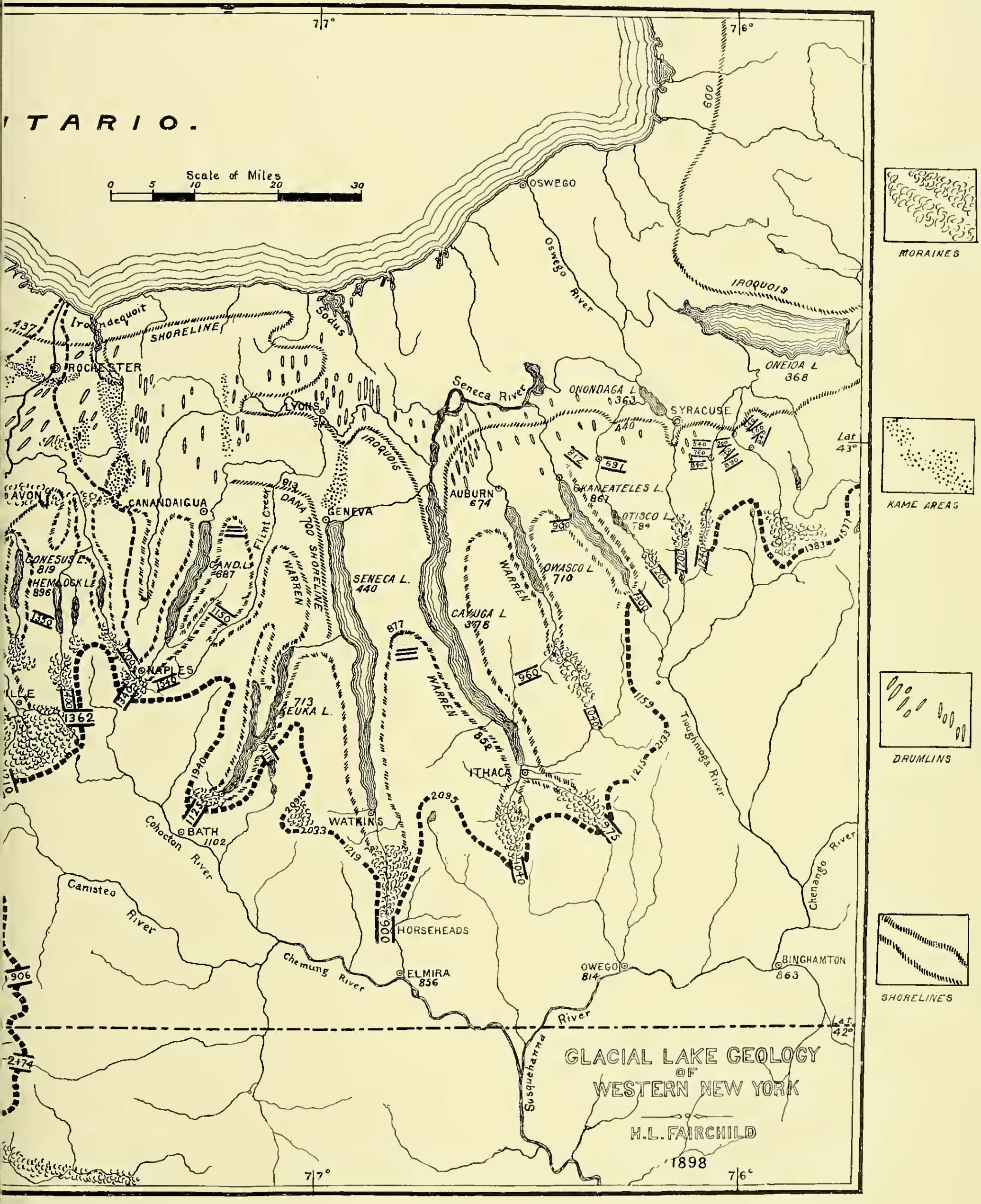

GEOLOGY OF WESTERN NEW YORK

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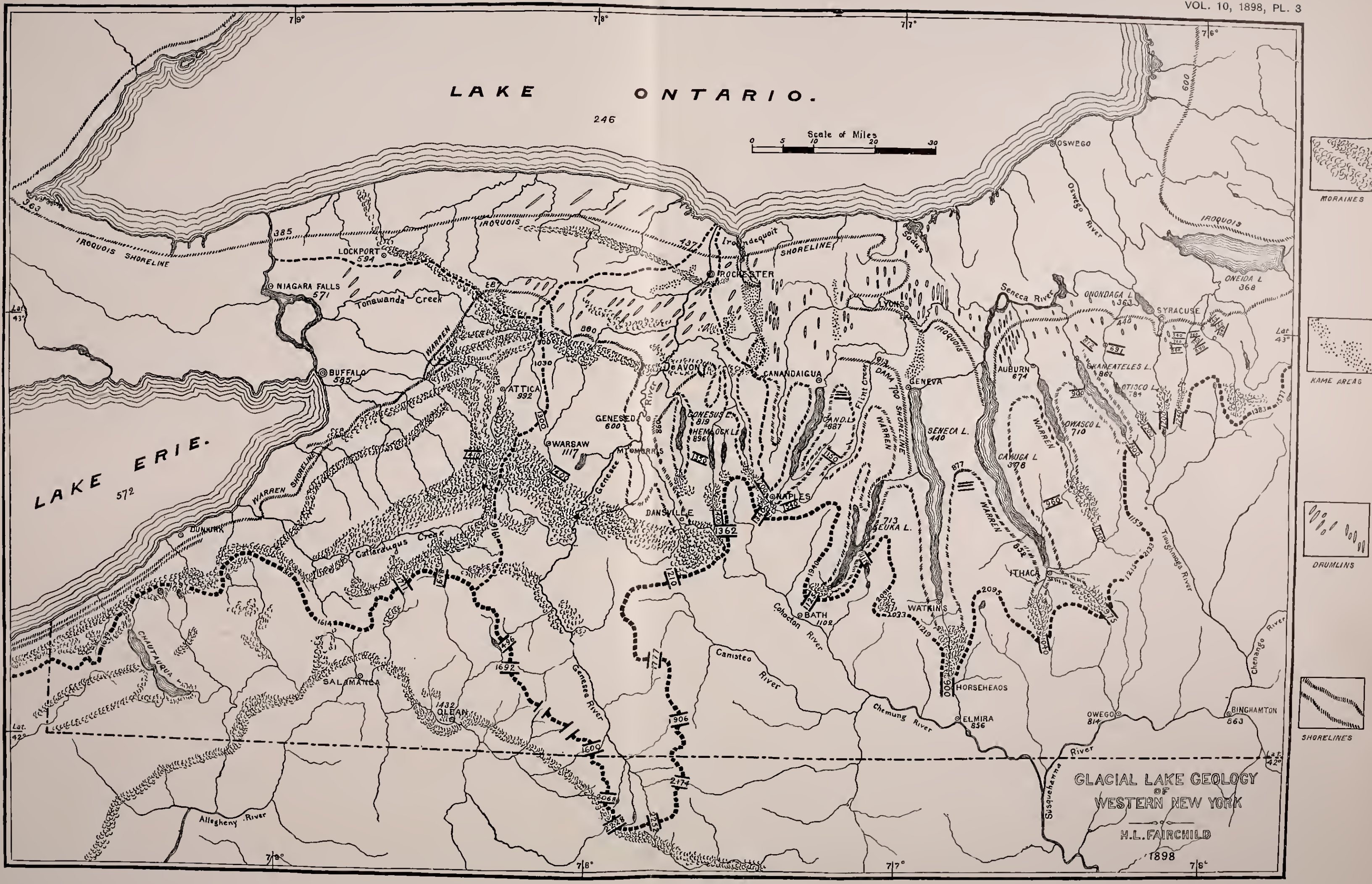

GLACIAL AND GLACIAL LAKE GEOLOGY OF WESTERN NEW YORK

Heavy broken lines indicate water-partings
Parallel bars indicate glacial lake outlets
Numerals show altitude in feet above ocean level
Drumlins are indicated to show the localities of their greatest
development and the direction of ice movement

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 10, PP. 27-68, PLS. 3-9 FEBRUARY 20, 1899

GLACIAL WATERS IN THE FINGER LAKES REGION OF NEW YORK

BY H. L. FAIRCHILD

(*Read before the Society August 23, 1898*)

CONTENTS

INTRODUCTION

In my former paper, "Glacial lakes of western New York,"* the glacial lake phenomena of western New York were treated in an introductory way, of necessity incomplete and somewhat theoretical. In subsequent papers † special features and restricted areas were described. So much of value and interest has since been learned concerning the lacustrine history of the area that it seems desirable to publish the present results as a review of the subject to date.

There still remain unstudied the extreme eastern and western limits of the area—that is, the valleys west of Tonawanda creek and those east of Butternut creek—and even within the studied area many points should be determined with more precision. Perhaps the most interesting matter relates to the history of the broader waters—the Newberry, Warren, and hyper-Iroquois lakes.

Unfortunately the topographical sheets of but a small part of the area have been published. Maps and sketches in black and white and without contours cannot satisfactorily indicate the lacustrine features, namely, channels, deltas, terraces, and beaches. Their significance rests largely in their relationship of altitude. Until the topographic sheets of the region are available, the reader must supplement the accompanying illustrations and an atlas of the state with large use of the scientific imagination.

The map has the same base as that with the former paper, but with addition of new data. The numerals show the present altitudes referred to ocean level. At cities and towns the elevation is that of top of rail at principal railroad stations. It is, however, important to keep in mind the fact that the present altitudes were not the altitudes of the same points during the time of the glacial waters. At that period the area under study was some hundreds of feet lower than it is today, and in the uplifting to present level it has not only risen as a whole, but has been

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* Bull. Geol. Soc. Am., vol. 6, pp. 353–374, April, 1895.

† Glacial Genesee Lakes. Bull. Geol. Soc. Am., vol. 7, pp. 423–452; Lake Warren Shorelines in Western New York and the Geneva Beach. Bull. Geol. Soc. Am., vol. 8, pp. 269–284.

tilted so that the water planes all rise to the northward, or east of north, at a rate of two to three feet per mile.

The local lakes were not of long duration and their surface level was unstable, changing with the downcutting of the outlets and with the greatly increased volume of the summer melting of the ice-sheet; consequently true beaches are usually wanting. The conspicuous evidences are the deltas of land streams with their terraces, embankments, bars and spits, and the outlet channels. East of Seneca valley the evidences are the same for the broader Warren and hyper-Iroquois waters, true beaches not having been found. The elevations of water-level in the eastern part of the area are mainly based upon the embankments and terraces, which, however, varied in their relation to the water surface. Some of the ridges parallel or oblique to the streams were probably on plateaus an uncertain distance above ordinary water; those transverse to stream channels and composed of well assorted or finer material were subaqueous and sometimes many feet below the surface. The study of these formations has not been carried to that degree of refinement whereby the vertical relation of the terraces and embankments to the water surface can be determined. The precise elevations given in the paper were found by spirit-leveling, unless otherwise stated.

Three shorelines are indicated on the map (plate 3). That of lake Iroquois, with an elevation from Rochester to Rome of about 440 feet, is represented as continuous, although from Sodus bay eastward it is immature and indeterminate; that of lake Dana, which theoretically extends westward throughout the Erie basin and eastward a little further than lake Warren, but about 190 feet lower than Warren, is indicated only where it has been continuously traced—on the west side of Seneca valley. The Warren shoreline has been traced with practical continuity as far east as the meridian of Rochester, and good delta phenomena have been found as far east as Owasco valley. The theoretical limits are indicated as far eastward as the great spillway of the hypo-Warren waters northeast of Skaneateles. It would have made the map confusing to indicate the still higher shoreline of lake Newberry, which should be traced about the valleys of Cayuga, Seneca, Keuka, and Bristol at about 100 feet over the Warren plane, and opening southward at the Horseheads outlet with 900 feet elevation.

General Description

The records of these extinct waters are the very latest phenomena connected with the ice invasion, and are the connecting link between the glacial condition and the present hydrography. This writing is chiefly a plain description of the more important features of these ancient lakes. The matter is of lively interest to perhaps only a few persons, but the details are necessary to the more general study of the Pleistocene. No economic or practical result from the knowledge is foreseen, but as pure science the study of these waterless lakes, waveless shores, and streamless channels has a fascination and romance. Its immediate results are of some value in helping to determine the conformation of the glacier front during its recession, and the deformation of the land surface since the shoreline features were produced.

A glacial lake is defined as a body of static water existing by virtue of a barrier of glacial ice. It will be evident upon slight reflection that such impounded waters can exist (1) where a glacier blocks a stream channel, or (2) where the general land surface inclines toward the glacier foot. Lakes of the first class have been described in Pennsylvania by I. C. White, in the Monongahela valley,* and by E. H. Williams, in the Lehigh valley † and the Susquehanna valley. ‡

All the lakes described in this paper belong to the second class. They were formed in the southern part of the Ontario basin, where the land slopes northward from a plateau of 2,000 feet elevation down to lake Ontario, 246 feet. The high plateau was deeply gashed by the preglacial stream erosion, and in these trenches along the northern border of the plateau lie the present "Finger" lakes. The topography was peculiarly favorable to the production against the bold ice-front of a series of distinct valley lakes, in many respects unequaled elsewhere.

The preglacial drainage of the region was northward and the heads of the rivers were probably much farther south than those of the present streams, perhaps even in Pennsylvania, like the present Genesee river. Theoretically, the oncoming ice-sheet met and blockaded the preglacial rivers and impounded their waters in the north-sloping valleys. The phenomena of those early glacial lakes caused by the advance of the glacier have been so destroyed or obscured by the overriding of the ice and by its debris that no certain evidences have yet been distinguished. We have therefore for our objective study only the lakes, far later in time, produced in the same valleys by the damming action of the ice-front in its retreat back to the north.

According to size and importance, the glacial waters which we have to consider may be divided into three groups: (1) *Primitive and smaller*

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* Origin of the High Terrace Deposits of the Monongahela River. Am. Geologist, vol. xix, p. 368, Dec., 1896.

† Extramorainic Drift between the Delaware and the Schuylkill. Bulletin of this Society, vol. 5, p. 286, March, 1894.

‡ Notes on the Southern Ice Limits in Eastern Pennsylvania. Am. Jour. Sci., vol. xlix, p. 183, March, 1895.

local lakes. As the ice-front slowly receded northward beyond the divide in any section, numerous lakelets were produced between the dissolving ice-front and the northward-facing land surface. Most of these were evanescent and have left slight traces. Some of them, at the heads of valleys, enlarged with the ice removal and may have existed long enough to produce outlet channels and other phenomena characteristic of standing water, but not beach forms, which require considerable breadth, depth, and permanence of the water body. (2) *Larger local lakes.* The greater north-sloping valleys were occupied by lakes of large size. Each of the present lakes collectively known as the "Finger" lakes was preceded by a much larger and deeper glacial lake, the surface being held up to the level of some outlet leading directly or indirectly southward. Similar lakes also existed in some valleys in which no water is ponded today. Some of these larger glacial lakes had a varied history and intricate relationships with their neighbors. The most complex and romantic lake-history belongs to the valley of the Genesee (see page 34). All of these lakes were destroyed by draining to the level of adjacent lakes or to the invading waters of the next group. (3) *Pre-Laurentian lakes.* The same agency which interfered with the free drainage of the New York valleys also blocked the flow in the great basins of the Saint Lawrence system. For a time separate waters were held in the southern or western ends of Superior, Michigan, and Erie basins, known respectively as the Duluth, Chicago, and Maumee glacial lakes.* Their ultimate overflow was into the Mississippi. With further removal of the ice-front, the Duluth and Maumee lakes were made tributary to or lost in lake Chicago, as this had the lowest outlet. The water in the Erie basin, succeeding lake Maumee, invaded the Ontario basin and our district of study as the glacial retreat permitted. This water is called lake Warren, and is believed to have covered all of the Erie basin, the lower part of Huron basin, and the southern and western part of Ontario basin. Its level in central New York is now lifted by the tilting of the land surface to about 880 feet. The local lakes in New York were blended and lost in the eastward creeping Warren waters, which retained their westward outlet via lake Chicago to the Mississippi until the removal of the glacier from the high ground near Syracuse permitted a lower escape to the Mohawk-Hudson valley.

When the eastward outlet of the Ontario basin was established at the lowest point, at Rome, New York, lake Iroquois came into existence. From the plane of lake Warren down to that of lake Iroquois was about 500 feet, and the lowering of the waters, which required probably many

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*Description of the glacial lake phenomena of the Laurentian basins will be found in the writings of F. B. Taylor, Warren Upham, G. K. Gilbert, J. W. Spencer, Frank Leverett, and others, chiefly in this publication, in the American Geologist, and in the American Journal of Science.

centuries, was by a series of leaps as the ice retreat opened lower passes. One long pause was established by a rock channel at Marcellus, which held a water-level herein named lake Dana (see page 56).

Such is the dramatic history, in epitome, of the glacial waters in central New York. The remainder of this paper is mainly a record of the observed facts, with only as much statement of theory and interpretation as is necessary to show the significance and relationship of the phenomena.

Enumeration of the Local Lakes

Name of present Lake or Stream	*Name of Glacial Lake*
1. Tonawanda creek	Johnsonburg, Attica, and Alexander.
2. Oatka creek.	Warsaw, two phases.
3. Genesee river..	Several successive lakes.
4. Canaseraga creek	Dansville.
5. Conesus lake	Scottsburg.
6. Hemlock lake	Springwater, two phases.
7. Canadice lake	Glacial Canadice.
8. Honeoye lake	Glacial Honeoye.
9. Bristol (Mud Creek) valley	Bristol.
10. Canandaigua lake	Naples and Naples-Middlesex.
11. Flint creek	Italy and Potter.
12. Keuka lake	Hammondsport, two phases.
13. Seneca lake	Watkins and Newberry.
14. Cayuga lake	Ithaca and Newberry.
15. Owasco lake	Groton and Moravia.
16. Skaneateles lake	Glacial Skaneateles.
17. Otisco lake	Glacial Otisco, Marietta, and Marcellus.
18. Onondaga creek	Cardiff (Tully Valley), South Onondaga, and Onondaga valley.
19. Butternut creek	Butternut, three (?) phases, and Glacial Jamesville.

Tonawanda Valley

Below Attica, or northward, toward Batavia the valley bottom is a broad plain with low walls, declining 100 feet in the 10 miles to Batavia. Southward the valley is narrow, with high steep borders, like the other north and south valleys of western and central New York. Up the valley eight miles lies the village of Varysburg, and two miles farther Johnsonburg. Two miles farther south the valley is wholly obstructed with morainal drift, and becomes indefinite, although the creek heads several miles still farther south.

In the section of Johnsonburg and Varysburg three water-levels are visible near stream deltas. The highest one has an estimated elevation of about 1,425 feet, the middle one about 1,300 feet; or about the same as Johnsonburg railroad station. The lowest one is near the valley bottom and bears the village of Johnsonburg, but is a little higher than Varysburg, two miles north.

The highest water plane correlates with a swamp col, an abandoned outlet on the western valley border, about two miles south of Johnsonburg and close to the flag station called Perrys. The Buffalo, Attica and Arcade railroad crosses the swamp a few rods east of the highest part. The channel leads west to Buffalo creek and the Erie basin. The height of this col is estimated at 1,410 feet. The lake held at this highest level should be known as the Johnsonburg lake. The outlets correlating with the two lower water-levels are unknown. They are probably on the western border. Probably the water of the middle level would cover the site of Attica and should bear the name of Attica lake, which was applied hypothetically to all the glacial water of this valley in the earlier published paper. In that case the waters impounded in the lower part of the valley and having the lowest level might be appropriately called the Alexander lake. The Attica lake received for a time the overflow of the Warsaw lake from the east.

OATKA VALLEY

The upper half of Oatka (Allen) creek lies in a typical preglacial valley commonly known as the Warsaw valley. With its steep ice-moulded slopes, its north and south direction, and its heading abruptly in a moraine, it is characteristic of those in western and central New York which held glacial waters. In several features it is the counterpart of the Dansville valley.

A few miles above Warsaw the valley ends abruptly in a moraine filling which is the northern edge of a broad belt of moraine drift traversing 50 miles of this section of the State. Excellent views of the valley, the moraine, and the glacial lake outlet are given by two lines of railroad. The Buffalo, Rochester and Pittsburg traverses, upon the east side, the whole length of the valley. The Buffalo division of the Erie passes through the head of the valley, entering from the south by the primitive outlet of the glacial waters, and leaving the valley, northwest of Warsaw, by the second or lower outlet. The Buffalo, Rochester and Pittsburg railroad crosses the Erie and the higher outlet by a trestle at the head of the channel. This ancient river bed is 15 to 20 rods in width and of good character, although somewhat obstructed by the cuttings and fillings of the two railroads. About a mile from the col the channel passes through the village of Silver Springs and leads southeast past Castile to the Genesee river.

The elevation of the head of the channel, according to the old profile of the Erie railroad, is about 1,400 feet. Near Rock Glen, a mile northward, at the head of the open valley, the drift is terraced at an elevation about 15 feet higher than the channel bottom. This water-plane shows well from the valley northward, and glimpses of it may be had from the trains on the Erie railroad. The high-level waters are called the Warsaw lake. These, however, did not long survive nor cover a large area, as with the recession of the ice barrier the water soon found a lower outlet northwestward across the western border northwest of Warsaw. This notch in the valley rim, utilized, as stated above, by the Erie railroad, leads to a small, north-sloping valley in which lie the villages of Dale and Linden. The elevation of this outlet is not closely determined, but by Erie datum it is not far from 1,300 feet.

With the first opening of this western pass the Dale-Linden valley was only flooded by the Warsaw high-level water, and it was a gulf of the Warsaw lake. With further recession of the ice-foot the ridge of land separating these waters from the Tonawanda valley on the west was uncovered and the lowering of the water-level finally made the second outlet effective. No good distinctive name is available for this second and lower level, and we may call it the second phase of the Warsaw lake. It was really a distinct lake, for while the water by the Silver Springs outlet found escape to the Genesee lakes and into the Susquehanna drainage, that by the Dale-Linden outlet was tributary to the Attica lake and ultimately to the great lake Warren and Mississippi drainage. Some traces of the work of these second phase waters are visible on the valley slopes where the land streams dropped their detritus.

The Warsaw lake was eventually destroyed by the removal of the ice barrier on the eastern border, and the lacustrine history of the lower or northern part of the valley blends with that of the seventh stage of the Genesee glacial waters.

Genesee Valley

The lacustrine history of the Genesee valley is remarkable, complex, and truly romantic. Reaching from Pennsylvania northward entirely across New York State and sloping from over 2,000 feet elevation down to Ontario level (246 feet), the valley held waters at many different levels as the ice barrier uncovered successively lower outlets on either side. The waters at various stages flowed into different drainage systems, east and west. At least ten stages are recognized of the Genesee glacial waters. In a separate article this valley and its lakes have been treated at length (see reference on page 28). In one point an addition is to be made to the former description. At least one stage of the hyper-Iroquois waters has been recognized in the Genesee valley (see page 57). In the enumeration of the Genesee lakes this should be inserted after lake Warren as the ninth stage waters and called lake Dana.

Canaseraga Valley

For the description of the glacial waters of this valley see the former paper, "Glacial lakes of western New York," page 358.

Conesus Valley

For the description of the glacial waters in this valley see the former paper, "Glacial lakes of western New York, page 360.

Hemlock Valley

Hemlock lake, the source of Rochester's water supply, is the successor of the ancient lake. The village of Springwater lies two and one-half miles south of the head of the lake and not far above its level. The side walls of the valley rise 800 to 900 feet above the lake, which has an elevation of 896 feet above tide, with the steep smooth slope characteristic of the ice-moulded valleys of the Finger lakes region. At the level of the former glacial lake surface the valley has a width of about one mile.

The only stream of note in the valley is the inlet creek, which has its origin near the divide, about one mile north of the village of Wayland. Some wet-weather streams along the sides of the valley have left inconspicuous deltas.

The moraine in the head of the valley extends from Springwater to Wayland, a distance of about four and a half miles. At the divide the drift is mainly gravel, although the topography is typically morainal. The water parting is near the east-and-west town-line road, nearly one mile north of Wayland, with an altitude of about 1,400 feet, taking the Erie railroad at Wayland as 1,387. The surface here is irregular, with kettles and small swamps. There is no swamp col and the water channels are narrow and tortuous, opening through Wayland into the broad channel south of the village where the Cohocton creek has its source. The later and more important outlet is on the west side of the valley.

An interesting feature of the Wayland locality is the extensive plain immediately south. This is one mile wide and extends southeastward from Perkinsville, several miles beyond Wayland. Much of the surface is underlaid with marl, which furnishes the basis of the famous Wayland cement. The divide lies about one-half mile west of Wayland, where the waters of the marsh find their way to either the Dansville or the Cohocton valleys.

The second outlet of the glacial Springwater lake was northwestward by a notch in the west wall of the valley, about one mile south of Websters station, on the Erie railroad, and two miles north of the Springwater station. Here is a good swamp col, about one-fourth of a mile wide, with a capacious channel leading northwest to the Conesus valley. The elevation of the col is about 1,350 feet. The Erie railroad follows this ancient waterway from Conesus station to near Springwater. During this second phase of the Springwater lake its waters were tributary to the Genesee lakes and they flooded the Canadice valley on the east. The correlation of the water-levels with this outlet and the subsequent lake history have not been studied.

It may be noted that the physical features and lake history of this valley are similar to those of the Warsaw valley; also that the two phases of waters are really distinct lakes with different drainage, the earlier higher lake draining south into the Cohocton creek and Susquehanna system, while the second and larger lake poured its surplus water westward into the Conesus valley and the Genesee lakes, although this ultimately also found its way into the Susquehanna.

Canadice Valley

The Canadice valley lies immediately east of the Hemlock valley and at a higher level. While Hemlock lake has an elevation of 896 feet, Canadice lake is 1,092 feet. The dimensions are also much less. The head of the Canadice valley is nearly on the parallel of the head of Hemlock lake and about three-fourths of a mile east, and the valley opens broadly into or blends with the Hemlock valley. The divide between the two has an elevation of about 1,200 feet. As this is 150 feet lower than the outlet of the Hemlock Valley glacial waters (Springwater lake), the glacial Canadice must have been, in the earlier stage, simply an arm or gulf of the former water.

With sufficient retreat of the ice-front it seems likely that the Canadice waters became isolated for a short time with escape across the valley border; but the phenomena have not been studied at the time of this writing.

Honeoye Valley

Honeoye lake occupies the bottom of a narrow, long, and deep north-and-south valley. The head of the valley is about three miles west of

Naples village. The divide is on land of Henry Rathbun, two and one-half miles from Naples and seven miles from the head of the lake. The water parting is a long narrow swamp col from which a good channel leads eastward to Naples. The elevation of the col is somewhat under 1,200 feet. During the earlier and higher phase of the Naples lake (glacial Canandaigua)* its waters flooded the Honeoye valley, which held consequently only a western arm of the Naples lake. The glacial Honeoye came into separate existence when the Naples lake was drained to a lower level by its eastern outlet toward the Flint Creek valley (see description on next page), this second outlet having an original elevation probably over 1,150 feet, but reduced subsequently by down cutting. A conspicuous delta west of Naples village was built by the Honeoye outlet stream, assisted by the West Hollow creek. No study has been made of the water-levels in the Honeoye valley or of its later lake history.

Bristol (Mud Creek) Valley

The deep Bristol valley, which carries the upper waters of Mud creek. lies between the Honeoye and Canandaigua valleys. The head of the main valley is at South Bristol, where it divides into two valleys, one leading southwest and heading in a moraine divide with elevation of about 1,600 feet, the other leading southeast to a divide with elevation of about 1,290 feet, one mile north of Bristol Springs. This lower divide was never the passage for any stream of water, but was low enough to permit the higher waters of the Naples lake to flood the Bristol valley.

Canandaigua Valley

The lacustrine phenomena at the head of the Canandaigua valley were described in some detail in the earlier paper. The glacial water, Naples lake, had a primitive elevation something over 1,350 feet. Its outlet was southward to Susquehanna drainage through a well formed channel near Atlanta railroad station, which has an elevation of about 1,340 feet. No corrections are here required, but a clearer interpretation of certain water-levels is given by the recent discovery of an outlet channel lower than the primitive one south toward Atlanta in the Cohocton valley. In the former description of deltas at Naples several well developed water-levels were described which did not correlate with the superior Atlanta outlet, and yet were far above the hypothetical Newberry plane. The explanation has been found in a channel cut by the escaping waters across the north and south ridge between the West River

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* See former article, Bull. Geol. Soc. Am., vol. 6, pp. 361–364.

(Middlesex) and Flint Creek valleys, and which drained the Naples lake eastward into the Keuka valley. This channel is a fine example of the excavations produced by the ice-dammed waters in their escape over low places uncovered by the receding ice-foot. It is a nearly straight rock cut, about one mile long and 100 feet deep, partly in Hamilton shales. It heads about one and one-half miles northeast of Middlesex village, near the east edge of a swamp col. A north and south road crosses near the head of the channel. The bottom of the channel is about 100 feet wide, flat, smooth, and swampy, with uniform gentle grade, falling perhaps 30 feet in the total length. The channel now carries no stream. The elevation of the col is not accurately determined, but is probably over 1,150 feet. The lower end of the channel is one mile northwest of Potter village, on the west side of Flint Creek valley. Here the ancient stream which cut the channel piled the debris into a large delta in the expanded waters of the Hammondsport glacial lake. This delta is further described below (see next page).

With the opening of this outlet and the down-cutting of the channel the Naples waters were so lowered that the Honeoye waters became a separate lake, tributary to Naples, and the delta west of Naples village was formed with strong terraces correlating with the Potter outlet. The waters of the Middlesex valley, which joins the Canandaigua valley southward, always remained an eastern arm of the Canandaigua waters.

This lower water body, with outlet at Potter to Keuka Valley waters, ought, strictly, to have a separate name. It was not really the Naples lake which overflowed at a higher level to the Cohocton river directly into southern drainage. In order to preserve the association we will call it the Naples-Middlesex lake.

The Newberry waters never existed in the Canandaigua valley (see page 43).

The Warren waters have left evidences about the shores in the form of delta terraces at elevations about 880 feet. A good beach of the Warren waters may be seen about one mile west of Reeds Corners, along the west side of the Canandaigua road, opposite the house of Mrs Gates and beneath the house of Mrs R. V. Henry. The elevation is about 880 feet.

Flint Creek Valley

The Flint Creek valley, lying between Canandaigua and Seneca valleys, impounds no lake at present, but its features and history are similar to those of the Finger lakes valleys. The north end of the valley is at Gorham village, partially blocked by moraine drift. From here southward to Potter, about 8 miles, the valley bottom is occupied by a cedar swamp, which may have been produced by the filling of a shallow morainal lake. At Potter the valley bifurcates, the larger and more direct branch leading nearly south and joining the Branchport arm of the Keuka valley. The col between these valleys is one mile south of Friend postoffice, with an altitude not closely determined, but of about 1,000 feet. A scattering kame-moraine stretches for three miles north of the col. The col is a swampy flat, but no good channel leads from it.

The southwest arm of the valley, known as Italy hollow, is a long, narrow, winding valley, which holds the headwaters of Flint creek. The divide at the head of the valley is over 1,500 feet elevation and only some two or three miles from Naples.

There seems no escape from the conclusion that the Italy branch of the valley must have held for a time a deep local glacial lake, with its outlet into the Naples lake at the highest level of the latter. We will call this the Italy lake. A well defined channel leads from the col, but soon descends rapidly as a ravine and bisects the ancient delta, situated southeast of Naples village. The latter was named in the former paper the Tannery Glen delta. The broad summit level of this delta has an aneroid altitude of about 1,370 feet, which correlates with the Naples lake at the highest level.

When the ice-front receded so as to uncover the junction of the two valleys at Potter, the Italy lake was lowered into some other water. There are reasons for thinking that its successor was the extended Hammondsport lake. The Flint Creek valley received for a time the overflow of the Naples-Middlesex lake, and the channel cut by the draining stream, described above (see page 38), piled the debris derived from the gorge excavation in a large and conspicuous delta close to Potter village.* The summit plateau of the delta has an elevation of about 1,150 feet. This is 150 feet over the col at Friend and correlates with the level of the higher waters in the Keuka valley (see next page).

The only objection to supposing that the Hammondsport lake extended north into the Potter section of the Flint Creek valley is the fact that the present outlet of Keuka lake, at Penn Yan, into Seneca lake, is farther south than Potter. But it should be understood that the northern end of the Keuka valley is contiguous to, and indeed blends with, the larger Seneca valley, and that heavy lobes of the ice-sheet lingered in the larger, deeper valleys of Seneca and Cayuga. It seems likely that the ice blocked the present Keuka outlet long after the ice was removed from the latitude of Potter. In no other way does it seem possible to

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*This delta, with an interesting kettle, which it includes, is made the subject of a separate paper, Kettles in Glacial Lake Deltas. Journal of Geology, vol. vi, p. 589.

hold the waters at Potter above 1,000 feet, the approximate height of the col at Friend.

The lower and main terrace of the Potter delta, with an aneroid elevation of 1,080 feet, does not correspond to any prominent water-level in the Keuka valley, but with accurate leveling and allowance for the differential uplift may be found to correlate with the col at Friend. This lower Flint Creek Valley water should be called the Potter lake.

Keuka Valley

Since publication of the former description of the Hammondsport lake, with its outlet south through Bath, fuller study of the region and the shorelines has brought to light new and interesting facts. The lake history of the valley is similar to that of the Canandaigua valley in respect to a second and east-side outlet and two stages of the local waters. This later channel passes through the village of Wayne, about two miles southeast of Keuka village and a less distance east of the present lake. It is apparently wholly in drift, but the channel features are well preserved. The col is immediately south of the Wayne cemetery, the altitude being, as measured by a recent survey for an electric railroad, 1,116 feet, Keuka lake surface being taken as 709. The definite channel heads about 60 rods below the cemetery, leads southeast through the western edge of Wayne village, and enters lake Wanetta, the whole length being less than a mile. The width of the channel at bottom is about 150 feet. The grade is gentle and cutting was not great as the chain of lakes in the valley south of Wayne, established a local baselevel and gave a check to erosion. The ultimate outlet was into the Cohocton river, the same as the earlier outlet at Bath.

On the eastern slope of the Keuka valley, something over a mile east of Grove Spring and about one and one-half miles west of Wayne village, two distinct shorelines have been traced for one-fourth of a mile, curving around the north-facing hill. These cross the east and west road diagonally, and are most distinct south of the road, on land of Mr Ezra Nickerson. They appear as beach ridges in front of wave-cut cliffs, and are composed of the triturated and decomposed shale of the hill.

The lower of these beaches or bars was found by spirit-level to have the same elevation as the head of the Wayne channel. The other ridge is 30 feet higher and is somewhat stronger and better defined.

The present difference in elevation between the Bath outlet and this later, east-side, Wayne outlet is not over 10 feet, according to the railroad surveys. However, the differential uplift between the two points must be 20 feet or more. The higher of the two Grove Spring beaches is thought to correlate with the Bath outlet and to have been formed during seasons of high water before the Wayne outlet was cut and lowered sufficiently to carry all the overflow.

The ancient land stream deltas are excellently displayed upon the slopes of the Keuka valley, and the elevation of benches have been measured by aneroid at Hammondsport and Urbana upon the west side and at Eglestons glen upon the east side. The terraces about the southern end of the valley correspond closely and fall into four distinct levels, which may be generalized as follows, taking the lake surface as 709 feet in August, 1897:

Summit plateaus in south end of valley....	1,145 ±	feet.
Higher gravel ridges and bars......	1,115 to 1,140	"
Main terraces..........................	950 to 965	"
Lower terraces..................................	825 to 865	"

The 1,145 ± plateaus are found only in the upper end of the valley and correlate with the Bath outlet, making allowance for differential uplift. Somewhat lower are found the embankments and frontal bars on terraces which mark the later level of the waters with the Wayne outlet. These correlate with the lower beach on the slope back of Grove Spring.

The main terraces are clearly those of the Newberry waters, which, to judge by the relative development of the benches, must have existed longer in the valley than the earlier lakes; the lower terraces as those of the Warren waters.

SENECA VALLEY

IN GENERAL

The topographic features of this central valley of the Finger lakes were described in the former paper with an account of the lacustrine phenomena at Horseheads and Watkins. It is now desirable to record with more detail the shore phenomena and to determine the lake succession in this most important valley of the central New York series.

SOUTH END OF SENECA VALLEY

No observations are to be added to the description of the Watkins-Newberry outlet at Horseheads, but shoreline phenomena have been studied at Montour Falls (Havana), in the southern part of the valley. This is the most southerly point at which any observations have been made of glacial lake shorelines in New York.

On the western slope of the valley, above the village and on the north side of the ravine, occur gravel bars of the Watkins and Newberry waters. The higher one is of good form, direction northeast-southwest, with an elevation (aneroid) of 950 feet. Ten feet lower are three short bars of clean, fine gravel.

On the south side of the same ravine occurs an excellent bar of lake Warren. It is a strong ridge, of good form and clear gravel, which enters the village cemetery at the upper or northwest corner, with direction northwest-southeast and elevation of 840 feet.

On the east side of the valley, southeast of Montour Falls, are excellent beaches, at altitudes corresponding to those on the west side. The higher (Watkins-Newberry) bars lie upon the north side of the Havana-Odessa highway, about half way between the villages, on land of Mr John A. Charles, and a few rods above the house of Mr Luther J. Drake. There are three bars only a few rods apart, the middle one being the strongest. The latter crosses the road obliquely, trending southwest, and may be easily located by a large oak tree that stands on the bar by the north side of the road. Taking as datum the top of rail at the Odessa station of the Lehigh Valley railroad as 1,092.32 feet above tide, the highest of the three bars, somewhat irregular and broken, is 940 to 942 feet. The middle and strongest bar is 935 feet and the lowest is 932 feet.

Bars of the Warren waters form the front of a terrace on the south side of the road on the north side of the famous Havana glen. These are behind the house of Mr Frank Doolittle. There are two ridges of nearly equal height, the outer one of excellent form, direction northwest-southeast. The line of levels from Odessa station makes the elevation of these bars 840 feet. By leveling across the valley, with proper corrections, these bars were found to accord with that in the Montour Falls cemetery.

WEST SIDE OF SENECA VALLEY

At Watkins the Watkins-Newberry levels are found in good form on the summit of the delta above the village, both sides of the Watkins glen. Above the cemetery, which is located on the terraces of the delta on the north side of the glen, the delta summit is a broad plateau of gravel, with rolling surface, with a handsome bar upon the edge; direction northwest-southeast. In 1894, by hand level, the elevation was made 961 feet; with aneroid, in 1897, it was made 955 to 960 feet.

On the south side of the glen the delta is wider and less definite, but displays several terraces near the summit with good bars. Taking the top of rail of the Fall Brook railroad on the viaduct across the glen as 1,022.40 feet, the higher series of good bars was made by aneroid 960, 952, and 950 feet. The middle bar is ten rods in front of the higher, with excellent form, and ends as a spit. The lowest is some distance farther east and farther from the ravine, curving, and with a small hook at its extremity. These three bars correspond very closely in their relationship to the three bars four miles southeast on the Odessa road. The difference in altitude is due to deformation of the land.

Twenty feet below the three bars there is another broad terrace, with a short but good bar upon the front.

The village of Himrods is about two miles from the lake and about midway of the length of the lake. A delta was formed in the high waters by the stream, which has subsequently cut a ravine through the village. The summit of the delta west of the village shows a beach ridge, on the south side of the highway, ending in spit points. The elevation, by aneroid, taking the rail at the station of the Fall Brook railroad at 847.28 feet, was made 990 feet.

The Warren shore is near the level of the railroad station, but its exact plane has not been determined. Just north of the station the railroad cuts a ridge which probably represents a delta terrace, having an elevation of 851 to 853 feet. North of the ravine is a ridge carrying the village cemetery, with an elevation of 839 feet. This probably was a deposit of stream and shore current during the extinction of lake Warren. The true Warren plane can doubtless be found at this locality by further search.

The village of Stanley, the junction of the Northern Central branch of the Pennsylvania railroad with the Naples branch of the Lehigh valley, is about four miles south of the parallel cutting the north end of Seneca lake, and is almost as far north as the Newberry waters ever reached. The shoreline of these waters may be seen about one mile southwest of Stanley, or about half way to Gorham, along the Lehigh Valley railroad. A north-and-south highway crosses the railroad at the summit of grade. A short distance on the road south of the crossing the Newberry waters have left a well marked shoreline cut in the drift. This correlates with a ridge and spit one-fourth of a mile farther southwest. A gravel pit has been excavated in this by the side of an east-and-west road. The same level of static water action is visible along the Stanley-Gorham road. Taking as datum the rail of the Lehigh Valley railroad at the highway crossing as 941.3, the elevation, by aneroid, of the wave-cut cliff is 970 and the crest of the bar spit 966 feet.

LAKE NEWBERRY EXTINCTION

Beach phenomena of lake Newberry have not been found west or north of Stanley. It is believed that these waters never passed beyond the high land between Seneca and Canandaigua lakes, but with the removal of the ice from the northern point of that ground the waters of lake Newberry were lowered to lake Warren. The east-and-west scourways which were made by the escaping Newberry waters in the extinction of that lake are found, cut across the drumlin surface, at a locality five miles southeast of Canandaigua and two miles south of Ennerdale station, on the Northern Central railroad. Here well marked channels lie athwart two north-and-south roads. The highest scourway is an indefinite channel at the four corners, one and a half miles east of Reeds corners, with an aneroid elevation of 985 feet. An excellent channel, 20 rods wide and truncating the south end of a drumlin, is found northward with elevation of about 950 feet (aneroid). About one-eighth of a mile farther north another good channel occurs, 30 rods wide, bordering the south side of a moraine and truncating the north ends of drumlins. The elevation is about 930 feet (aneroid). These channels seem to prove that lake Newberry was destroyed by the extension of lake Warren into the Seneca basin. The volume of water drained through these channels was considerable, as lake Newberry had a large area and was lowered through 100 feet of its depth.

THE "GENEVA" BEACH

In another publication * description has been made of a strong beach along the west side of the Seneca valley. This was first discovered above Geneva with elevation of 700 feet, and was traced north and west to near Shortsville, with some evidences of the water-level as far west as the Genesee river. Since the time of that publication the beach has been traced south along the west slope of the Seneca valley as far as the Keuka lake outlet. It lies along the east side of the north and south Preemption road from Geneva to near Bellona, a distance of over six miles, except that north of Billsboro village the beach lies obliquely across the road. It is more or less broken by embayments, but in places is a heavy ridge. A mile from Bellona the beach swings eastward, and on account of the steeper valley slope it lies less than a mile from the present lake. East of Bellono and three-fourths of a mile west of Earles station, on the Fall Brook railroad, the beach passes beneath the house and barn of Edwin Earle. South of his house it crosses obliquely to the east side of the road and for five miles pursues a nearly direct course parallel with the Seneca shore. It now becomes weaker and is traceable with difficulty. A mile from Dresden it curves westward up the embayment of Keuka outlet. The most southerly point of the shoreline phenomena of this water observed at this writing is near Mays Mills, on the Penn Yan branch of the Fall Brook railroad. The beach

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* Bull. Geol. Soc. Am., vol. 8, pp. 281-284.

seems to pass beneath the house occupied by Mr Ezra Decker, and in the field in front of the house is a strong bar on a delta parallel with the creek. Taking the railroad at Mays Mills as datum at 556 feet, the elevation of the bar is 650 feet. Three miles north, near Angus station, the bar is 671 feet, using the railroad datum. About three miles farther north, at Mr Earle's, the well formed beach of apparently full height is 679 feet. About seven miles farther north, at Geneva, the full height of beach by Mr Bean's, on the Preemption road, is 700 feet, taking as datum the top of rail of the Lehigh Valley track crossing of the Preemption road as 606.92 feet. By the same railroad datum, using the rail at Phelps as 600.82, the heavy bar at the reservoir of the Phelps water works, five and one-half miles northwest of the last point, is 713 feet.

Careful research will undoubtedly reveal the Geneva beach farther south in the Seneca valley. This beach is now correlated with an outlet at Marcellus, and the water is named lake Dana (see page 56).

EAST SIDE OF SENECA VALLEY

At Burdette, about one-half mile west of the railroad station and just west of the village, the Newberry shoreline is found at the head of the steep slope, on the north side of the ravine. The highway is crossed by an irregular kame-like ridge in which is a gravel pit on the south side of the road. Southward from the gravel pit the ridge is a good bar. Passing by a till knoll as a shelf or cut terrace, and then curving around to the west parallel to the ravine, it rapidly descends and ends as a very bold spit facing the valley. An old cemetery is located upon the extreme point of the spit. Behind the bar, near the road, is a broad kettle basin.

Taking as datum the Lehigh Valley railroad at the station as 1,001.62, the elevation of the bar is 964 feet. This is thought to represent nearly the true water-level.

The slope of the valley is so steep that the formation of shore deposits at lower levels was not favored, and the Warren shoreline is not found at the theoretical level. Somewhat lower, however, is a terrace in the delta with a bar front having elevation of 828 to 832 feet.

Below this the slope is precipitous, and the Geneva beach is not shown.

Upon the south side of the ravine a distinct bar lies at an elevation (aneroid) of about 935 to 940 feet.

At Hector station the Newberry shoreline is above the railroad. Taking the rail as 919.52, the bar on the south side of the highway.on land and close to the house of Mr A. B. Nivison, is 976 feet elevation. This is on the north side of the ravine. Higher up the delta is another ridge at elevation of 990 feet, behind which is a large and deep kettle. This bar forms the front of an extended plateau of water-laid drift, with low ridges parallel and close to the stream channel. This plateau may represent the highest or initial level of the Watkins lake.

Across the ravine or southward are three bars, the lowest being the strongest, with a difference of elevation of 10 feet. Their absolute elevation, however, is at least 10 feet lower than the Nivison bar.

The Warren level is shown as a plateau in the little village below and west of the station, with an elevation of about 830 feet. North of the northern ravine a heavy ridge of coarse material occurs in the orchard and behind the barn of Mr B. J. Budd, with elevation of 871 feet. Below this is a poorly formed ridge at 864 feet.

At North Hector station, immediately north of the station, the delta gravels have been extensively excavated, giving a vertical exposure of about 100 feet and well displaying the delta structure. The Newberry level is the summit of the dissected plateau, where a heavy bar-spit is found, on the north side of the road, with elevation of 984 feet, the station being 872.22 feet. Behind this transverse bar is a broad basin of low ground. This bar seems to correlate with the high bar at Hector, two miles south, and may represent the primitive Watkins level.

The railroad station is a few feet over the head of the Warren plateau, which averages about 865 feet (aneroid).

The village of North Hector lies a mile westward, near the lake, on a series of delta terraces. The broadest of these terraces is thought to represent the waters of the lake Dana.

At Lodi, one quarter of a mile east of the station, and just beyond the cemetery and schoolhouse, are three bars, showing best upon the south side of the road. Taking the top of rail at the station as 784.62 feet, the elevations of these ridges are 854, 865, and 874 feet. The highest ridge is the largest, and is taken as the best representative of the Warren level.

One-half mile farther east and half way to Lodi village a strong bar crosses the road, beneath the house of Mr James Gulick. The elevation is 977 feet and it represents the Newberry waters.

At Ovid the top of rail at the station has an elevation of 857.52 feet. The beach of lake Warren is 19 feet higher, or 877 feet. This shows east and northeast of the station as a good spit. South of the station the beach is faint, but shows clearly farther westward where it curves around the hillside. It crosses the east-and-west road, in the northwest part of the village, beneath the house of Mr Patrick Smith, and is a good shoreline farther south. The drift of the region is only a thin veneer over soft shales, from which it was apparently derived, and the material of the beach is largely a shale gravel, which at the surface, especially in

GULF CHANNEL

Bare limestone at intake, looking northeast (upstream)

long cultivated fields, has disintegrated into a rather stiff soil quite unlike an ordinary beach.

The shoreline of lake Newberry passes through the village of Ovid. The natural surface of the ground has been so changed that the exact location and elevation of the beach has not been found. Probably the main north-and-south street in the business portion of the village is near the beach level, and the concave slopes of the drumlins on which stand the court-house and the academy are the wave-cut cliffs. The Newberry beaches will probably be found east of the academy, also southwest of the village.

It was at this point that the Ithaca lake was extinguished and the waters of Watkins lake took possession of the Cayuga valley, thereby inaugurating lake Newberry. This is discussed farther on (see page 49).

Cayuga Valley

DETERMINATION OF WATER LEVELS

The later work in this valley has been the determination of the water levels at a few localities. The highest level, that of the local Ithaca lake, has not been studied recently.

The delta at Coy Glen, in the inlet valley near Ithaca, was used in the former paper relying upon the Ithaca sheet of the topographic map for elevations. By careful instrumental leveling, using the Lehigh Valley railroad as datum, the rail on bridge over the inlet creek near the delta being 393.7 feet, the broad flat terrace correlating with the Warren level was found to be 865 feet elevation. Below this is another good bench at 831. Other benches occur at 737 and 654, and a broken terrace 618 at the head down to 580 at the point.

At Willow Creek station a small stream built some terraces at the successive water-levels. Below the station of the Lehigh Valley railroad is a sloping terrace with gravel ridges generally parallel with the ravine ending lakeward as bold spits or bluffs. These occur both sides of the ravine near the house of Mr Horace Sutton, and together they form an extended bluff of gravel. Taking the rail at station as 747.62 feet, the head of the gravel ridges is 622 feet, and they terminate at 611 feet. This bluff is regarded as indicating a sublevel of the Geneva Beach waters (lake Dana).

About one-half mile up the slope west of the station delta gravels are well displayed both sides of the ravine at levels marking the position of Warren waters. The lower terrace underlies a vineyard on the south side of the ravine opposite a tenant-house of Mr H. F. Owen. The frontal bars are 825 feet and the good heavy bar at back of terrace is 829 feet elevation. The higher gravels are found both sides of the ravine near Mr Owen's residence. No transverse bars were seen, but heavy gravel ridges that diverge obliquely from the ravine. These have the form of bars and the material is well assorted gravel. The lowest bar heads by the lane leading to the house and ends eastward in a broad lobe by the south side of the east-and-west road; its elevation at head is 863 feet, at end 859. The full height of the stronger bars is seen west of the lane on a fair terrace, with elevation of 877 feet, and somewhat higher toward their head. These higher ridges may have belonged to the flood-tide delta that was above the lake-level.

At Taughannock Falls station (top of lower rail 833.02 feet) the action of the Warren waters is shown in excellent form. East and south of the station and both sides of the ravine are handsome bars. The highest has an elevation of 849 feet. South of the ravine this is a strong curving gravel ridge, crossing the highway and supporting the barn belonging to Mrs R. Wilcox. North of the ravine it forms the highest part of a broad plateau of fine soft gravel. This plateau declines lakeward, with ridged surface, and about 60 rods east ends abruptly with an excellent frontal bar. This bar curves around the edge of the terrace, reaching clear to the ravine, with convexity lakeward; its elevation is 826 feet. A corresponding level is found on the south side of the ravine, where beyond a depression a heavy ridge lies under the house of Mr Henry Luckey, with elevation by aneroid of 830 feet.

The village of Trumansburg is built on a broad delta plain of the Newberry waters, and bars are well developed both sides of the ravine which passes through the village. On the north side the bars appear between Congress and Prospect streets. The lower and heavier bar crosses Prospect street, supporting the houses of Mr Davenport and Mr North on the east side of the street. This bar forms the north edge of the bluff-like terrace at this place. Northwestward it crosses Congress street and runs against higher ground. Landward two other lighter bars appear only a few rods apart and a few feet higher. Taking the top of the Lehigh Valley rail at the station as 876.22, the frontal bar is 956 to 958 feet and the inner bar, perhaps 15 rods distant, is 962 feet elevation.

South of the ravine a good bar is found crossing South street obliquely, trend south 30 degrees east, in front of the house of Mr Ver Planck, occupied (1897) by Mr Woodward. Its altitude is practically the same as those on the north side of the village. The general level of the village plateau is very little higher than the bars.

The Warren level shows as a heavy bar below or east of the railroad station. The southern branch crosses the east-and-west road at the house of Mr C. M. Dickerman and strikes the ravine road under the houses of Mrs Tallmadge and Mrs Sawyer. To the west the ridge ends as a spit, facing lower ground. The elevation of this bar is 834 feet. The frontal ridge forming the northern branch is 829 feet.

ITHACA LAKE EXTINCTION

Ovid village lies on the north point of the high ground separating Cayuga and Seneca valleys. This is the critical point in the relation of the glacial waters of the two valleys. We find here a set of phenomena and a succession of events in the lacustrine history similar to those described above referring to the extinction of lake Newberry. We are, however, taking the general events in reversed order of time, as the Ovid phenomena, to be described, refer to a time anterior, possibly by many centuries, to that of the scourways near Canandaigua. The Ovid phenomena relate to the origin of lake Newberry; those near Canandaigua to its extinction.

South of the village the north-and-south drumlin ridging is broken and east-and-west channels appear. The highest and broadest is about one and one-half miles south and the lowest seems to be in the village. The elevations have not been measured nor a close examination made of these channels, but it is confidently believed that they are the scourways eroded by the escaping waters of the Ithaca lake. While the ice-sheet covered this northern end of the dividing ridge between the Cayuga and Seneca valleys the waters of the Cayuga valley (Ithaca lake) were held up to a level of the White Church outlet, southeast of Ithaca, with present elevation of 975 feet. When the ice melted back from the ground south of Ovid the Ithaca waters found there an outlet about 60 feet lower and made haste to escape westward along the ice-front into the Watkins lake. When this subsidence was accomplished and the waters of the two valleys became confluent, then lake Newberry, the expansion of the local Watkins lake, occupied the Cayuga valley.

OWASCO VALLEY

The present Owasco lake is eleven miles long, with elevation of 710 feet. The city of Auburn lies two miles beyond the north end of the lake and some distance beyond the end of the definite valley. The valley bottom extends seven miles south of the lake, to the village of Locke, and then rises for eleven miles to Freeville, where the valley is intersected by an east-and-west depression, drained by Fall creek westward into Cayuga lake.

At Locke a narrow valley branches southwest from the main valley and heads in a swamp col near north Lansing. Beyond the col is the valley of Salmon creek, which enters Cayuga lake at Ludlowville. The elevation of this col is given by the Moravia sheet as 960 + feet. The elevation of Freeville, at the col of the main valley, is 1,040 feet.

Before the glacier foot had receded as far as Locke a small lake must have been held in each branch of the valley. The one in the main valley may be called the Groton lake.* This had its outlet into Fall creek, at Freeville. The elevation of the water surface was about 1,045 to 1,050 feet. The phenomena have not been studied in the Groton branch, but delta terraces may be found about Groton and Peruville.

The smaller lake held in the narrow western branch, at an elevation originally of perhaps toward 1,000 feet, was the predecessor of the Moravia lake, which occupied the greater valley until the ice-dam was removed from the high ground between this and Cayuga valley, at a locality about six miles south of Auburn.

Good deltas and water-levels are found at Locke and Moravia, but especially at the latter village. At Locke the best plateau is south of the village, being the point at the junction of the two valleys. It is triangular, about one-third of a mile across, and nearly level; at least the point is water-laid drift. The elevation, taking the rail at the Lehigh Valley station as 795, is 860 at the front and about 870 at the back. This seems to represent the Warren level. Other plateaus of similar level are seen up the valley southeast.

Along the sides of the valley are seen traces of eroded terraces, both of the Warren level and of another much higher.

At Moravia deltas are well developed and two water-levels are conspicuous. The largest delta is close to the village on the east side, where a gravel excavation has given a vertical exposure of about 100 feet. The broad summit plateau of this delta, both sides of the ravine, has an altitude of about 1,000 feet at the front and rises landward only 15 to 20 feet in half a mile. This is the proper level of the Moravia lake, making some allowance for the down-cutting of the outlet, the depth of water over the sill, and the land deformation through eight miles of distance.

The lower terraces at Moravia represent clearly the Warren level. There are two benches 27 feet apart. The extended upper bench corresponds precisely on both sides of the ravine, having an elevation of 882 ± feet. The lower bench, with an elevation of 855 ± feet, appears only on the south side of the ravine. This is the plateau beneath the house of Mr Spofford.

These two Warren terraces show plainly, looking from the village, on

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* In the earlier paper this name was applied to the glacial waters in the whole Owasco valley. It is now regarded as the proper designation of only the earlier, more localized lake, while the later and main lake should be called the Moravia lake.

FIGURE 1—VIEW FROM THE LOWER HIGHWAY, CROSSING CHANNEL, LOOKING NORTHWEST (UPSTREAM)

FIGURE 2—VIEW NEAR MOUTH OF CHANNEL, LOOKING EASTWARD (DOWNSTREAM)

GULF CHANNEL

the profile of a delta some three-fourths of a mile south. The measured difference upon the delta is still 27 feet.

No evidence was found at Locke or Moravia of the Newberry water, but the study of the valley is too slight to form any conclusion from the evidences as to the existence of lake Newberry in this valley. *A priori* the chances seem about even, for the 1,000-foot contour line west of Owasco is on quite the same parallel as the point near Canandaigua where lake Newberry found its death. It, however, seems probable that lake Newberry was lost in lake Warren before its waters could gain access to Owasco valley. If they did reach the valley they existed there but a relatively short time.

SKANEATELES VALLEY

The lake of this name is some 15 miles long and varies in width from three-fourths of a mile to one and one-half miles. The village of the same name lies around the foot of the lake. Except on the west side of the northern part, the valley has steep and unbroken walls, and the upper half of the valley is remarkably narrow and deep. The elevation of the lake is 867 feet.

At near the middle of the lake on the west side is a low notch, slightly over 900 feet, which was the outlet of the glacial waters during the later phase of the local lake. Before this pass was opened the waters in the higher southern end of the valley were held up to a level about 450 feet higher than the present lake, and were forced over the divide at the headwaters into southern drainage.

The headwaters divide is a mile south of Scott village and about three miles south of the head of the lake, on the east side of the ancient valley. The col is not a swamp but is among morainic knolls. The channel is not wide, and has been obstructed by detrital cones at the mouths of gullies, but is evidently an ancient waterway. It was not required to carry a large volume of glacial water. The channel leads into Factory brook, which, flowing south to Homer, 6 miles, joins the Tioughnioga river.

The present elevation of the col is about 1,300 feet. No effort has been made to find any shoreline phenomena of this high level, but delta terraces can probably be found in the region of Carpenters Falls, on Bear Swamp creek.

As there is no village in the upper valley that lies below the ancient lake-level, we are compelled to call the lake the glacial Skaneateles.

When the diminishing ice-lobe was lifted from the low notch above mentioned the waters were lowered 400 feet. This pass is interesting in structure and relations and important in its clear evidence concerning the history of the broader glacial waters. The col is one-third of a mile west of the present lake shore, at the hamlet called Mandana, six miles south of Skaneateles. It is a swampy channel, about 30 rods in width, with a gravelly floodplain one-third of a mile wide, and 10 to 15 feet higher. Westward from the divide the plain declines and is cut and channeled. The narrow and deeper channel is on the north side of the col. The Skaneateles sheet of the topographic map makes the divide a little over 900 feet elevation.

One-half of a mile west toward Owasco village the channels terminate in a broad plain of detritus that was spread out by these streams (and by Dutch Hollow brook from the south), in an arm of the Warren water, which then filled the Owasco valley. This detrital plain is 20 to 30 feet lower than the Mandana col, or about 870 to 880 feet in elevation. At the time of these events lake Newberry was not in existence, but had been extinguished in lake Warren. This would not prove that the pass when first opened might not have been flooded by the Newberry waters, but some examination of the stream ravines on the Skaneateles slopes convinces the writer that the Newberry waters never invaded this valley. The Warren waters did, however, invade the valley from the north for a short time before their extinction.

Otisco Valley

Otisco lake, the most easterly of the Finger lakes, is about five and one-half miles long and three-fourths of a mile wide. It occupies only the central portion of a much longer valley of great depth. The elevation of the lake is 784 feet, while the ridge between Otisco and Skaneateles, only two and one-half miles through if tunneled at the lake's level, is over 1,900 feet high. The valley extends north 7 or 8 miles beyond the lake, past Marcellus village, and the head of the valley is equally far south of the lake. A moraine occupies the head of the valley and another moraine, with remarkably heavy transverse ridges, fills the lower part of the valley northward from the lake for over three miles, beyond which it has been buried under delta deposits or swept away by powerful streams.

The col at the head of the valley, with an elevation on the Tully topographic sheet of about 1,200 feet, is about two miles north of Preble village. The outlet channel is on the west side of the valley. It is a well defined scourway, 20 to 40 rods wide, and with bordering gravel plains, 20 to 40 feet higher, all the way to the broader valley at Preble. No examination of the valley has been made with reference to the shoreline phenomena of the high-level waters, which, on account of the steepness of the valley walls and the small drainage area, will probably be weak. The lake we may call the glacial Otisco. The lower part of the valley contains, however, heavy deltas, and is related to the great channels and other critical phenomena connected with the extinction of lake Warren.

Near the village of Amber, at the foot of the lake on the east side, are conspicuous terraces. The elevation of these is given on the Skaneateles topographic sheet as between 940 and 960 feet. Upon the faces of the deltas is a notching, 50 or 60 feet lower. The Amber deltas were built by rivers which drained the glacial waters of the Onondago valley, lying east. The lake in which the deltas were deposited, which we will call the Marietta lake, seems to have had its level determined by some winding channels in shale rock two miles due east of Skaneateles village, with elevation on the topographic sheet of 940 feet (see figure 1). This outlet carried the waters over to the Skaneateles valley by a fall of only about 20 to 30 feet, from whence it escaped still westward by the Mandana channel (see page 52) to the Warren waters, by a fall of about 30 or 40 feet. Other deltas formed in the Marietta lake occur two miles south of Marcellus, on the east side of the valley. The Marietta lake was succeeded in the Otisco valley by the Warren waters at full height, which produced the lower notching on the Amber deltas.

EXTINCTION OF LAKE WARREN: HYPER-IROQUOIS WATERS

Two miles south of Marcellus village a huge delta lies on the west side of the valley at the mouth of a great channel cut in the Hamilton shales (see plate 5). The topographic sheet gives the height of the delta terraces as 860 down to 800 feet. The delta is the debris derived from the excavation of the gorge and dropped by the powerful river in the slowly falling waters of the Otisco valley. The gorge heads four miles northwest of Marcellus and a mile west of Sheppards Settlement on limestone, with an elevation at the intake, as given by Dr Gilbert, of 812 feet.* Here at the head of the eroded "gulf" (the only local name) the drift and shale are removed down to the hard limestone rock over considerable area (see plate 4). It is evident that an enormous volume of water escaped at this point. This was the water of lake Warren, which

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*The channels and deltas at the foot of the Otisco valley were first brought to the writer's notice by Dr Gilbert in 1896. These and the other large channels farther eastward, described later in this paper, were studied by Dr Gilbert and briefly noted in his paper in the Bulletin, vol. 8, p. 285. Through the kindness of Dr Gilbert and the courtesy of the United States Geological Survey several of Dr Gilbert's photographs of the channels are used in illustration of this article. These include the views in plates 4-7 and figure 2 of plate 8.

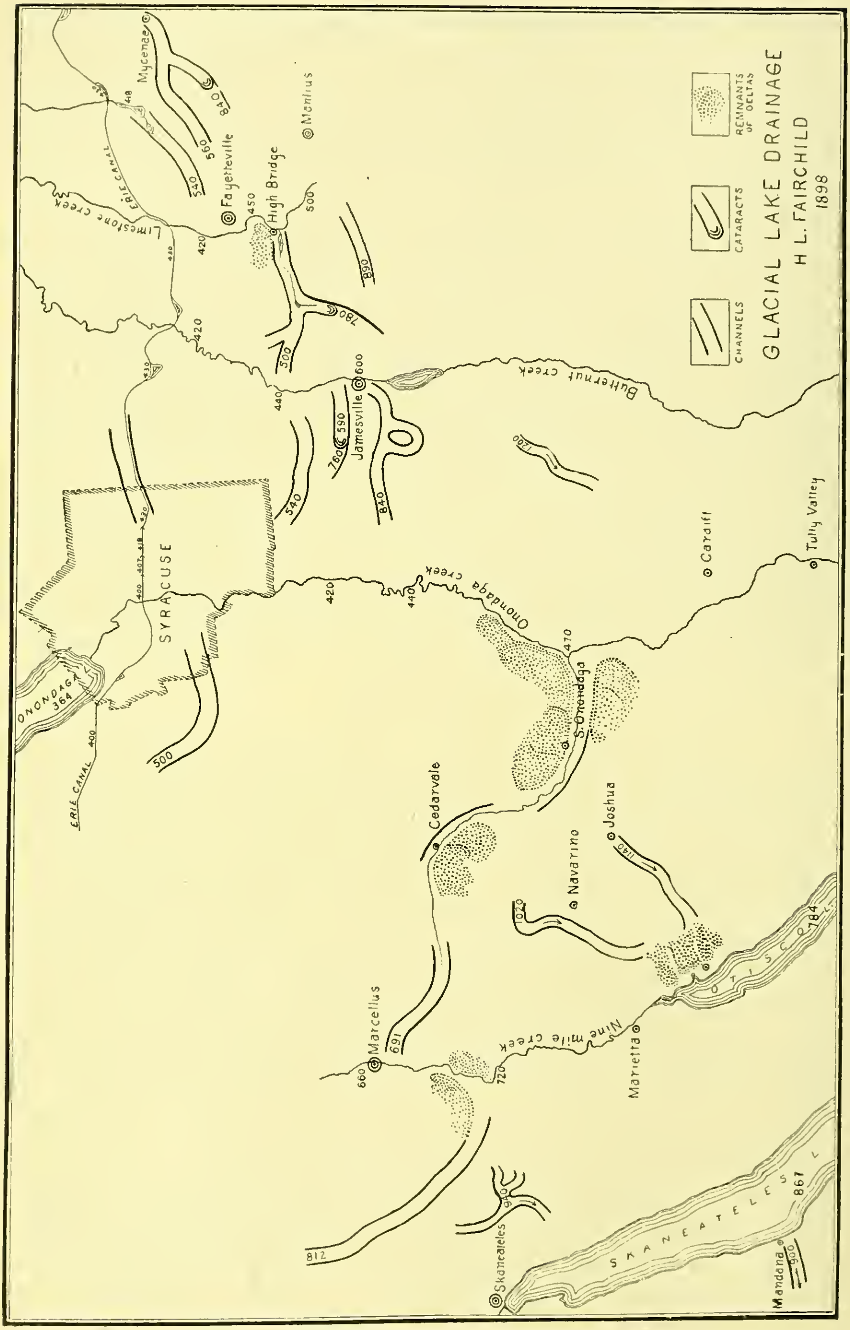

Figure 1—*Hyper-Iroquois Channels.*

FIGURE 1—HEAD OF CHANNEL, NEAR MARCELLUS, LOOKING EAST (DOWNSTREAM)

FIGURE 2—VIEW LOOKING NORTHWEST (UPSTREAM) FROM SOUTH ONONDAGA

CEDARVALE CHANNEL

found here an outlet lower than its old one westward across Michigan to the Mississippi. Its western flow, that had been sustained perhaps some thousands of years, was by the removal of the ice-dam in this region slowly reversed and shifted to the east toward the Mohawk-Hudson. This was the end of lake Warren proper. For the similar body of water, but with falling surface and diminishing area, which found lower and lower outlets eastward along the ice-front, we can have no specific name, but using a generic term may speak of it as the hyper-Iroquois waters.

The Warren overflow into the Otisco valley would have been quickly checked if some eastward outlet were not provided. This is found in another rock gorge, which we call the Cedarvale channel, that leads southeast from Marcellus to the Onondaga valley. A great part of the excavation of this gorge was done *pari passu* with the cutting of the Gulf and by the same water, but the initial height of the outlet must have been less than the height of lake Warren.

It seems probable that the Warren waters had obtained access to the Otisco valley, and even to the Onondaga valley, before the lower passes further east were opened; in other words, the ice barrier was removed from the pass at Sheppards Settlement before it was lifted from the passes south or southeast of Syracuse. This succession of events would account for the absence of scourways, below 900 feet elevation, across the north-and-south ridge west of the head of the Gulf. When the lower eastern escape was finally opened, probably by the channels near Jamesville, the Warren waters in the Otisco and Onondaga valleys quietly fell until the Gulf outlet became effective, the waters entering from the north by two valleys separated by a drumlin ridge, the eastern of the two valleys eventually taking all the overflow. Theoretically the Warren waters entered this region with an elevation more than 880 feet. Evidence of erosion at near this level appears in a cliff on the west side of the valley one mile south of the intake, which has the appearance of stream cutting. This is near Mud pond. On the east side of the channel, at the east-and-west road one-half mile below the intake, is a gravel plain at 880 ± feet, which is probably a floodplain of the early river.

The body of water held in the Marcellus section of the Otisco valley during the life of the Gulf river we will call the Marcellus lake, it being the third glacial lake of the valley. The surface elevation of this water was determined by the heights of the Cedarvale outlet. The down-cutting of this outlet during the life of the Marcellus lake will account for the succession of terraces on the Gulf delta, south of Marcellus, ranging from 860 down to 800 feet, and for the several stream-cut cliffs on the southeast and eastern faces of the terraces worn by the currents in their northward flow to reach the Cedarvale escape.

LAKE DANA

The growth of the Gulf delta, which had been northward in the direction of flow, was terminated by the cessation of the Gulf river. This was caused by the further recession of the ice front, allowing the hypo-Warren waters to enter the Otisco valley directly from the north. This change had no effect upon the Cedarville channel, which remained effective. When in the down-cutting of the Marcellus shales the underlying limestone was reached, a check was given to rapid erosion, and the great lake that had here its outlet became comparatively stationary for a long time. It is believed that this was the lake which produced the Geneva beach * (see page 44).

The head of the Cedarvale channel is at the southeastern edge of the village of Marcellus. It is about 50 feet above the Nine Mile creek, and leads directly away from the valley with a width between one-fourth and one-third of a mile (plate 6, figure 1). About 50 rods east of the north-and-south road that lies on the channel head the rock sill was excavated by a cataract to a depth of 30 or 40 feet. The deepened channel trends east for nearly one-half mile, then narrows to perhaps 700 feet and trends southeast for a mile, widening to 1,200 feet, then takes an eastward course and spreads out into a branch of the Onondaga valley, where the great delta was built. The channel bottom is now concave and the erosional form destroyed by the wash from the walls of decomposing shale. The lower part of the later channel, after it had trenched its earlier delta, is shown in plate 6, figure 2.

The rock strata at the head of the channel dip southward. On the north side of the intake the limestone is exposed, but on the southern and lower part of the rock sill the Marcellus shale is not wholly removed, but cut into three shallow channels with two intervening ridges of shale. Taking as datum the United States Geological Survey bench-mark on the coping of the bridge in the village as 653 feet, the elevations at the intake are as follows:

Limestone sill at road corners, north side	696	feet.
Channel, 15 rods wide (not entirely open)	684	“
Ridge of shale	690	“
Channel, 3 rods wide (only a hollow)	684	“
Ridge of shale	689	“
Channel, 8 rods wide (free)	685	“

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* See Bull. Geol. Soc. Am., vol. 8, pp. 281–284.

The height of the rock sill at the intake is practically that of the tops of the ridges, and averages 691 feet. The limestone exposed at the northern angle of the channel head will average about 700 feet elevation.

The correlation of the Geneva beach with this channel at Marcellus is wholly theoretical. Only uncertain evidences of the Geneva Beach water have been seen east of the Seneca valley, but doubtless because no serious search has been made. However, our knowledge of the problem is sufficient, with the aid of the topographic sheets (partly unpublished) of the critical region in the vicinity of Syracuse, to give great confidence in the accuracy of this correlation. It is desirable to have a distinctive name for this important stage of the hyper-Iroquois waters, and it is proposed to name it after the eminent man who led American geologists in the adoption of the glacial theory and in making glaciology a branch of geologic science, and to call it lake Dana.

The extent of this lake remains to be determined, but it probably occupied the area of lake Warren, diminished by a fall of about 180 feet. This will carry it westward throughout the Erie basin, but not into the Huron basin. Search should be made for faint evidences 180 ± feet under Warren level.

Lake Dana existed many years, perhaps a century, or several centuries; yet, as compared with lake Warren, it had a brief life. It came to its close by the melting away of the ice-front from the district between Marcellus and Syracuse sufficient to allow eastward escape of the hyper-Iroquois waters through a lower pass than the Cedarvale channel.

ONONDAGA VALLEY

This valley was the basin of a glacial lake with early outlet southward through the depression occupied by the Tully lakes. The valley has a length, from Syracuse to Tully, of about fifteen miles, and is much more irregular in form than the other north-and-south preglacial valleys. A wide branch on the west, the South Onondaga valley, carries the west branch of the Onondaga creek. A heavy moraine heads the valley and extends from the divide at the Tully lakes northward for two miles. The Onondaga creek rises some miles west of the valley, which it enters by a ravine at the north end of the moraine filling. Like all the drift at the heads of these eastern valleys, the moraine is very gravelly, and the hills are really kames. The head of the divide is not a swamp col, but an area of knolls, with only indefinite channels, being in this regard like the divides at the head of Cayuga inlet, Keuka, Canandaiga, Hemlock, and Warsaw valleys. The water-parting was originally north of all the Tully lakes, which naturally drained south. The elevation of the divide is about 1,200 feet. The smaller northern lakes seem to occupy kettles in the moraine filling. The outlet channel may be regarded as beginning below the lower lakes—Crooked lake and Tully (Big) lake, which have an elevation of 1,193 and 1,189 feet. These are shallow, and probably lie in depressions due to ice blocks. The Tioughnioga valley, which heads at this point, will be discussed, with its heavy detrital deposits, at some future time.

In some features the Onondaga valley duplicates the Otisco valley. The ingress of Warren and Dana waters was by the great Cedarvale channel from the northwest, with a great north-curving delta; the egress of those waters was by a series of rock channels leading east from near the north end of the valley, south of Syracuse. There had been a similar overflow of the earlier middle-height waters to the west and a reception of waters from the east-lying valley, Butternut creek.

The waters which were held at the highest level in the Onondaga valley were called in the former article the "Tully Valley" lake, after a hamlet of that name five miles north of the divide. This name is equivocal and it is here proposed to substitute the name of another and larger village, lying two miles farther north, and call the high waters the "Cardiff" lake.

The Cardiff lake continued until the ice-sheet had receded as far as South Onondaga, when the waters found escape westward, to the Otisco valley, by a pass at Joshua about 60 feet lower than the Tully channel, or 1,140 feet. The swampy col is one-half mile southwest of Joshua postoffice, and the narrow but good channel leads southwest to Amber, at the foot of Otisco lake, where it deposited a delta with conspicuous terraces at 940 feet elevation (see figure 1). With a little farther removal of the ice-dam, another similar but larger channel was opened 120 feet lower. The swamp col is one and one-half miles, northwest of Navarino village. The channel, about 20 rods wide, leads south, close to Navarino, on the west, and enters the Otisco valley just north of Amber, its delta lying against the Joshua river delta and having the same elevation, 940 feet. This second glacial lake in the Onondaga valley, pouring its waters west ultimately into Lake Warren, may be named after a village in the valley, South Onondaga lake.

Further recession of the ice-sheet allowed the Warren waters access to the valley by the Marcellus-Cedarvale pass, probably holding them for a time at the Warren level, 880 + feet, and subsequently, when eastern escape was opened, receiving them by the Cedarvale river and discharging them eastward by the channels near Jamesville. Subsequently and for a long time the waters of lake Dana followed the same course through the valley. This third lake may be named "Onondaga Val-

Figure 1—View near Head of Channel, looking West (Upstream)

Figure 2—View of the Loop Branch, looking Southeast

RESERVOIR CHANNEL SOUTHWEST OF JAMESVILLE

ley " lake, after the southern suburb of Syracuse. The elevations of this lake and of the terraces of the Cedarvale river delta were ordered by the heights of the series of outlets southeast of Syracuse, near Jamesville, which are described below.

CEDARVALE CHANNEL AND DELTA

These are the finest examples of such combined phenomena in western New York. The head of the channel and upper, narrow, rock excavation near Marcellus have already been described (see page 56 and plate 6, figure 1). The total length of the present channel from Marcellus to South Onondaga is about nine miles, of which the lower six is mostly a broad preglacial valley that the Cedarvale river filled with delta drift, and subsequently reexcavated in part. The delta is of magnificent size and form, even in its present fragmentary state. It is separated into two great masses. The higher and upper portion is a great plateau south of Cedarvale postoffice, with area of more than one square mile. The terrace which forms the head of the delta is indicated on the Tully sheet by the contour of 860 feet. Lower extensive terraces eastward are 840 and 820 feet elevation. The southeastern third of this great remnant is a broad plain of 680 feet elevation. Evidently the broad open valley west of Cedarvale must have been filled with delta drift. A conical mound, over 40 feet high, of cemented gravel, stands conspicuously in the open valley, one mile northwest of Cedarvale, as a witness to the general filling at the sub-Warren level and subsequent erosion by the Cedarvale river. A stretch of open valley about one mile wide, excavated by the later stream, separates the Cedarvale delta mass from that at South Onondaga. This village is situated on a 600 feet terrace of a great island-like plateau, having a summit level of about 770 feet and an extended eastern terrace of 660–670 feet.* This mass is over a square mile in area. Still lower terraces stretch east and then north two and one-half miles, with faces cut by stream action similar to those in the Marcellus valley. These lie partly in the Onondaga Indian reservation. South of the creek and south and southeast of the village of South Onondaga is a broad delta plain somewhat over 640 feet elevation, with lower terraces southeastward. The head of this southward delta plateau was built by a southern stream pouring down the valley slope from Joshua, 500 feet higher. The power of this lateral stream is exhibited in a highway excavation where the deposit is a mass of boulders ranging in size up to two and three feet in diameter.

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*These figures of altitude about the Onondaga valley are taken from the unpublished Tully and Skaneateles sheets of the New York topographical map and may require some correction; but they are sufficiently accurate to discriminate the several delta levels and correlate them with the determining outlets.

Standing on the delta it is seen, much more plainly than the above figures indicate, that the several terraces fall under three general levels. The highest, 860 feet and downward; the middle, 770 feet and downward, and the lower from 680 feet downward to, perhaps, 500 feet. These three levels correlate with east and west rock channels that drained the Onondaga Valley waters eastward into Butternut valley, and which may now be very briefly described. The channels are shown in figure 1, page 54.

CHANNELS NEAR JAMESVILLE

The highest of these old waterways heads about one mile northeast of Onondaga Castle postoffice and leads east over two miles, to the Butternut valley, south of Jamesville, and opposite the reservoir, after which, in default of a better name, we will call it the Reservoir channel (plate 7). At the divide the channel is cut about 100 feet in Marcellus shale, with a floor width of about 30 rods (plate 7, figure 1). Land of Mr Charles Byrnes forms the north wall of the cut at the divide, which is given an elevation on the unpublished Tully sheet between 840 and 860 feet. At the edge of the Butternut valley the descending channel reaches the limestone, and the ancient river had a cataract there of 40 or 50 feet descent.

In the earlier work of this river it made a southward loop around a great drumlin mass, and during most of the life of the river the drumlin was probably an island. The loop channel forms more than half a circle three-fourths of a mile in diameter, is of excellent form and of interesting relation to the more direct waterway (plate 7, figure 2).

About one mile north of the Reservoir channel is another scourway across the high ground having a summit elevation of about 760 feet. This becomes about a mile north of west of Jamesville a gorge in the limestone headed by a semicircular cataract cliff 160 feet high and 400 feet across the amphitheater (plate 9, figure 1). In the depression excavated by the falling water lies Green lake, 60 feet deep. Professor Quereau has named the gorge the Jamesville gorge and renamed the lake Jamesville lake.*

The third and lowest of this set of channels (plate 8) lies a little over one-half mile north of the Jamesville gorge. In its altitude, form, preservation of features, and accessibility to observation, it is the handsomest glacial lake outlet channel in the State. The western end of the channel (plate 8, figure 1) is three miles southeast of the center of the

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*This channel, with its singular cataract phenomena, has been described by Professor E. C. Quereau, in a paper entitled "Topography and History of Jamesville Lake, N. Y.": Bull. Geol. Soc. Am., vol. 9, p. 173. In this paper he also describes briefly the general topography of the region and the relation of the postglacial channels to the preglacial valleys.

city of Syracuse, and the mouth of the channel is something over one mile north of Jamesville. It is traversed by the Delaware, Lackawanna and Western railroad, and is well shown on the Syracuse sheet of the New York Topographic map. It is two miles long, 800 to 1,000 feet wide at bottom, and 125 to 150 feet deep (plate 8, figure 2). The nearly vertical bare walls of limestone have given it the local name of "Rock cut." The term "railroad" channel will be more distinctive, since it is the only channel so utilized of the series here described. Unlike the channels in shale, merely the edges of the channel floor are covered by a talus. The floor is very nearly level throughout the breadth and length of the channel, with an elevation on the topographic sheet over 540 feet. It lies about 130 feet above the Onondaga and the Butternut valleys.

The following table will indicate the correlation that fuller study of the phenomena and closer determination of altitudes will undoubtedly confirm:

Elevations of principal terrace levels on Cedarvale-South Onondaga delta.		Elevations of outlet channels.		
			Initial.	*Present.*
Upper level	860	Reservoir	900 (?)	840+
Middle level	770	Jamesville	(?)	760±
Lower level	680 to 500	Railroad	700 (?)	540—

The lower part of the Onondaga valley, toward Syracuse, shows water levels from the Railroad channel level down through lower hyper-Iroquois levels to the later Iroquois 440 ± feet.

Butternut Valley

GENERAL CHARACTER

Like the Onondaga valley, the Butternut valley impounds at present no lake of consequence. This is a narrow, deep, curving valley reaching from four miles north of Jamesville south to Apulia, a distance of about 16 miles, and traversed by the Syracuse branch of the Delaware, Lackawanna and Western railroad. The primitive outlet of the glacial waters is at the head of the valley near Apulia station. Here is a very extensive gravel moraine or kame area at the junction of four valleys. The swamp col is one mile south of Apulia station and the channel leads southwest past Tully village and joins the outlet of the glacial Onondaga at the head of the Tioughnioga creek. This channel is a well-defined and capacious waterway below the col for some distance, but nearing Tully the deeper and later channel is curving and narrowed. The railroad lies in this primitive channel its whole length. The altitude of the col is 1,240 ± feet. Some inconspicuous delta terraces are visible from the railroad upon the east side of the Butternut valley, but no study has been made of the water-levels. The walls are steep and the side streams weak, and the shore phenomena is not pronounced. There are no villages in the valley, and the lake may be named the Butternut lake.

The Apulia outlet probably remained effective while the ice barrier receded 10 miles, or to within 3 miles of Jamesville. Then a somewhat lower pass westward was uncovered, which has been cut to 1,200 + feet elevation, according to the Tully sheet. This channel is about four miles south-southwest of Jamesville and the divide is upon a north-and-south road near the house of Mr Edward Russell. It is a rock channel, in shale, perhaps 15 rods wide at the col, leading southwest, then northwest, and debouching into the Onondaga valley at the Indian village. It carried the waters of the second-phase Butternut lake over westward into whatever waters then occupied the Onondaga valley, either the Cardiff lake or most probably lake Warren (see figure 1, page 54).

The local Butternut waters were possibly drained to a third level by an eastward-leading channel two miles east of Jamesville and on the south side of the Manlius road. Being by the "Green" station of the New York State survey, it may be called Greens channel. Here is a trench 20 rods wide in the black shale which carried the overflow of Butternut waters east-northeast to the Limestone valley at Manlius. The exact elevation of this waterway is not determined, but it is in the neighborhood of 890 feet. The initial height of the overflow was probably 50 feet above the present channel bottom. The reasons for not confidently regarding this channel as primarily a member of the hypo-Warren or hyper-Iroquois series are: (1) its probably too great initial elevation, and (2) its position. The relative position and trend of the several large hyper-Iroquois channels (see figure 1) and the orientation of the drumlin masses indicate that the ice-front had a trend somewhat northeast and southwest, and the Greens channel might have been open for eastward escape of the high local Butternut waters, while the Reservoir channel was still ice-covered and the Warren waters barred from the Butternut valley. However, it is possible that this cut was deepened by the eastward escape of Warren waters, and if so it was the first spillway. The honor of being the channel of first eastward flow certainly lies between this Greens channel and the Reservoir channel. This can not be positively determined without better knowledge of the relative land deformation and the precise elevation of the Warren plane in this locality and a close examination and comparison of the two channels.

By way of review of the glacial lake history up to the stage now under

FIGURE 1—HEAD OF CHANNEL, NEAR SYRACUSE, LOOKING EAST (DOWNSTREAM)

FIGURE 2—VIEW FROM HIGHWAY, SOUTH SIDE OF CHANNEL, LOOKING NORTHEAST (UPSTREAM)

Delaware, Lackawanna and Western Railroad in background

RAILROAD CHANNEL

discussion, it should be remembered that previous to this time all the glacial waters to the west of this meridian, except the primary local lakes and lake Newberry (which lakes flowed south across the divide) were drained westward, ultimately into the Mississippi. But during that time of westward flow lake Warren had crept eastward along the ice-front as far, probably, as the Onondaga valley, with a surface elevation between 880 and 900 feet, and the local lakes had one by one been destroyed by lowering into the invading Warren waters. The Mohawk valley was now apparently cleared of ice, at least sufficiently to allow of eastward drainage to the ocean, which then occupied the Hudson valley. The critical locality, where the glacier last dammed the Warren waters from eastern flow, seems to have been east and west of Jamesville. When the ice-front over the Butternut and Limestone valleys receded as far as Jamesville, the Warren waters found their first eastward escape toward the Mohawk, and all the waters of the Finger lakes region were suddenly diverted from westward flow to eastward flow.

The earliest eastern outlet of lake Warren extinction was possibly the Reservoir channel, the Warren waters standing in the Otisco and Onondaga valleys. If it was the Greens channel, then the Warren waters were also occupying the Butternut valley. But with the down-cutting of the eastern outlets the waters lowered upon the pass over the Corniferous escarpment west of Marcellus, at the head of the Gulf channel, and this became for considerable time the topmost wasteweir of the series of eastward-leading channels.

The later waters held in the Butternut valley, contributed successively by the three great channels leading from the Onondaga on the west, may be called the glacial Jamesville lake. Its level was falling as the eastern outlets changed.

The east-and-west ice-front was probably so close to the rivers flowing east through the Jamesville channels that the waters were practically forced across the narrow Butternut valley and the land eastward, and we find corresponding channels to Limestone valley, which will now be described.

CHANNELS LEADING EAST FROM BUTTERNUT VALLEY

The earliest of these waterways has been already described as the Greens channel (page 62). If this carried Warren waters, then it was the first eastward escape, and it was not in continuation of any river flow from the west. The water brought into the valley by the Reservoir channel during the early life of the latter was carried out by a channel one and one-half miles east and northeast of Jamesville. At the second road corners east of the village this may be seen as a broad scourway in the limestone with a northeastward direction. The east bank of the old river is conspicuous, but the west bank is less definite, as the ice-sheet limited the river upon that side. North of the road the channel is bare limestone where the river had rapids in its hastening to the cataract that may be seen about one-half mile north of the road. The canyon from the cataract leads north over one-half mile to White lake, and then swings east-northeast to the limestone valley at High Bridge, one mile south of Fayetteville. The cataract will be shown upon the Tully topographic sheet, while the canyon is depicted upon the Syracuse sheet. The channel at the intake near the road corners is 780+ feet, according to the map. We will name this the High Bridge channel. This channel was abandoned while the Reservoir channel was yet effective, as the mouth of the latter, south of Jamesville, is cut broadly into the rock at a lower level, about 650 feet.

No entirely separate channel corresponds east of the Butternut valley with the Jamesville canyon. The escaping waters seem to have laved the retreating glacier front and to have cut a series of cliffs on the southeastern shore as they flowed toward the High Bridge channel.

A western branch of the High Bridge channel forms a fairly direct eastward continuation of the Railroad channel. The intake is given on the Syracuse sheet as 500+ feet. This is a broad scourway in decomposed Salina shales, leading by rapids to the High Bridge gorge at White lake. The north side of these channels is not adequately portrayed by the 20 feet contours of the map, nor is the morainic topography.

A third or northwest branch of the High Bridge channel is a few feet lower than the western branch, and was the latest waterway leading east from the Butternut valley. The High Bridge river built a delta in the Limestone valley at High Bridge. The summit plateau northwest of the village is given an elevation on the Syracuse sheet of 500 feet.

The Butternut valley is so narrow at Jamesville, being scarcely more than a ravine, that it afforded scant space for delta accumulation, and the debris was probably carried on by eastward flow, while later streamwork carried any lingering detritus north into Iroquois waters.

Channels leading East from Limestone Valley

The last members of this remarkable series of channels occur northeast of Fayetteville, and they carried the falling waters out to the open Iroquois plain. There are two gorges, the higher and earlier having two branches. These are depicted on the Chittenango sheet. The earliest canyon heads as a cataract (plate 9, figure 2) two and one-half miles east of Fayetteville, on the east side of a north-and-south road, with an elevation at the rapids of 840+ feet. The cataract and canyon head are comparable to those of the Jamesville gorge, being of lesser depth and without a lakelet. The bottom of the amphitheater and canyon is a smooth meadow. The canyon leads northeast one mile and joins the east-and-west Pools Brook hollow, which has an elevation somewhat over 520 feet, and opens near Mycenae upon the plain at 460 to 480 feet elevation. The western end of this hollow, toward Fayetteville, is apparently obstructed with knolly drift. The col is about one mile east of Fayetteville, with an elevation of about 560 feet.

Northeast of Fayetteville, about one mile, is the head of another channel, with elevation by the map of 540 feet, which leads quickly down to the low plain 400 to 420 feet. Round and Green lakes, which lie in the channel course, the latter with 418 feet elevation, have been examined by Mr Gilbert, who pronounces them sinks due to underground drainage.

These easternmost channels may have been deserted, due to earlier removal of the ice barrier from this locality, while the Railroad channel and perhaps the High Bridge channel were still effective.

It will be observed that the Mycenae channel terminates at a level above that of even the later Iroquois.* Dr Gilbert has noticed this and suggested a baselevel of water in the eastern Ontario basin due to an ice-dam in the Mohawk valley. The suggestion is here offered that perhaps a lobe of the ice body lying in the Oneida lake depression pressed against the high ground northeast of Oneida village, and so held the pre-Iroquois waters of this locality higher than the Rome col. If this be so, there should be broad waterways between Oneida and Rome at an elevation over 500 feet.

On the north side of these lower eastern channels the drift is decidedly morainal, much more so than is indicated by the topographic sheets. This is especially the case with the two channels east of Fayetteville and with the High Bridge channel.

Hyper-Iroquois Channels near Syracuse

The fall of the glacial waters in the Ontario basin from the Warren level (880+ feet) to the primitive Iroquois level (440— feet) was by a series of leaps, as the retreat of the ice-front uncovered successively lower channels toward the Mohawk valley. The district from 15 miles southwest of Syracuse to 12 miles east was the critical region, apparently

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* It should be understood that the primitive Iroquois had a lower level on its southern border than the later lake, on account of the lower altitude of the Rome outlet, and that during the long life of the Iroquois its waters transgressed this shore and buried many features under the great silt plain.

because a broad expanse of the low Ontario plain (400± feet) meets abruptly the elevated plateau, and here the ice-body lingered in its last effort to dam the Huron-Erie-Ontario waters from the Mohawk-Hudson valley.

The water escaping eastward from the Onondaga valley by the two higher of the Jamesville group of three channels, the Reservoir and Jamesville gorges, was contributed by the hypo-Warren flood from the west; but the supply for the Railroad channel came from lake Dana through its outlet, the Cedarvale channel.

The succession of events and relationship of channels subsequent to lake Dana have not been determined. The history is partially obscured in the low Syracuse district by the changes in hydrography that have occurred since the ice removal. These are: (1) the possible existence of a pre-Iroquois water body, with elevation toward 500 feet, and consequent deltas and silting; (2) the primitive Iroquois, with elevation much under 440 feet; (3) the rise of Iroquois to 440 feet and consequent filling of former channels, and (4) the stream erosion subsequent to Iroquois throughout western New York.

Dr Gilbert has noted some east-and-west channels which are supposed to be the "tracks of Erian drainage" along the ice-front subsequent to the Dana episode. The one on the Marcellus meridian next lower than the Cedarvale gorge is conspicuous along the Auburn branch of the New York Central railroad from west of Marcellus station to beyond Camillus. Between Halfway and Marcellus stations the channel becomes a canyon with an estimated altitude of the bottom of about 450 feet. This debouched beyond Camillus into the low plain (400 feet), now occupied by Onondaga lake (364 feet), but then probably flooded by the earlier and lower Iroquois.

A channel apparently earlier than the Camillus gorge, but much later than the Reservoir gorge, passes directly through the heart of Syracuse, with an elevation of 400 feet. The head of this channel is one mile east of Fairmount, at the Solvay Process Company's cable road, in Salina shale, with an elevation of about 500 feet. This might have been a continuation of the earlier Camillus river before it had cut its canyon.

Land Warping in Western New York

Precise altitudes of the several shorelines have not yet been secured from sufficient number of far separated localities to yield exact data concerning the deformation of the whole area.

Over the region of the upper Great lakes the general trend of the isobases or lines of equal deformation have been calculated by Mr Taylor,

FIGURE 1—HEAD OF JAMESVILLE CHANNEL

View of lake and amphitheater, from the south side, looking northwest

FIGURE 2—HEAD OF HIGHEST BRANCH OF MYCENAE CHANNEL, LOOKING EAST FROM CREST OF CATARACT

The dark bands are shadows of trees.

EXTINCT CATARACTS

and accepted by Dr Gilbert, as west 27 degrees north by east 27 degrees south. The general direction of greatest uplift is normal to this or north 27 degrees east. In western New York, including the Seneca valley, the isobases drawn between fairly well determined points of equal elevation on the beaches of lakes Newberry, Warren, and Dana have a direction lying between 17 degrees and 20 degrees south of east. This indicates that the isobases of the greater area are curving lines with convexity southward. In a recent paper* Dr Gilbert has so represented them.

Data are now lacking for the accurate projection of the older water-planes eastward of the Seneca valley, but the subsequent Iroquois shore phenomena indicate but little east-and-west deformation, or, in other words, that the direction of tilting, so far as the Iroquois plane is involved, is not far from north-and-south in central New York. The Iroquois beach from Hamilton, Canada, with elevation 363 feet, to Rochester, New York, elevation 437 has an average rise of 0.66 foot per mile along a line less than three degrees south of east. At the same rate of uplift the Iroquois plane should have at the Rome outlet, which lies slighlty north of the parallel of the beach at Rochester, an elevation of more than 510 feet. The elevation of the channel floor at Rome is about 440 feet. It therefore seems likely that in central New York the isobases of the later Iroquois are not straight lines, but curves with convexity toward the south. Probably the older water-planes will be found to have, east of the Seneca valley, isobases trending about 10 or 15 degrees south of east.

In the Erie basin the Warren plane trends from Hamburg to Crittenden about 50 degrees east of north. Regarding the beach elevation at Hamburg as 815 feet and at Crittenden (at Lehigh Valley railroad station) as 858 feet, with a distance of 23 miles, the average rate of uplift is 1.87 feet per mile. The most northerly point of the Warren beach in New York is 11.5 miles from Crittenden along the same line, with an elevation of 887 feet, giving an uplift of 2.52 feet per mile. From Hamburg to the northernmost point of the beach (south of Smithville station on the West Shore railroad) the average uplift is therefore a trifle over two feet per mile in a direction 23 degrees nearer the isobase than the theoretical direction of maximum uplift, north 27 degrees east. The latter would be by calculation, 2.17 feet per mile and proportionally greater as the isobase is nearer the parallels.

Only in the Seneca and Cayuga valleys do we have sufficient north-and-south distance upon the shorelines in central New York to make any estimate of value regarding the northward uplift. The shoreline phenomena are, in those valleys, chiefly wave-built embankments on

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*G. K. Gilbert: Recent Earth Movement in the Great Lakes Region. Eighteenth Ann. Rep. U. S. Geol. Survey, p. 604.

delta terraces. Altitudes of water-planes based on such phenomena contain an element of error, the uncertainty of the vertical relation of bars and spits to the water surface. In the long stretches of shorelines about the great lake basins this error may be neglected, but it becomes serious in the short distances here available. The Watkins-Newberry phenomena have also another factor of error. The down-cutting of the Horseheads outlet caused a lowering of the water-level. As this was effected during the retreat of the ice-front, it is expected that the higher Watkins-Newberry phenomena should decrease in original altitude toward the north, and therefore would apparently decrease the effect of subsequent northward land uplifting. This error does not pertain to the Warren phenomena, and the latter have been most relied upon in estimating the amount of deformation, although it has been found that the clearer Newberry bars have in general about the same height above the Warren, namely, 100 feet.

In the Seneca valley the considerable number of accurately determined elevations permit generalization regarding the north-and-south deformation, notwithstanding the uncertainty in individual cases of the vertical relation to the water-level. In the southern half of the Seneca valley the deformation of the Newberry and Warren levels is about 1.5 feet per mile north-and-south, but in the northern half of the same valley the Dana beaches on the west slope show a northward uplift of 3 feet per mile.

It appears, therefore, that either the Seneca valley has suffered local warping or that there is a northward increase of the amount of tilting over the broader area. Both may be true, and the latter seems probable, since Dr Gilbert finds that the deformation of the Iroquois beach northward from Syracuse is 5 feet per mile.

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PLANATION AND DISSECTION OF THE URAL MOUNTAINS

BY F. P. GULLIVER

(Presented before the Society August 23, 1898)

CONTENTS

A RECONNAISSANCE

During the excursion of the Seventh International Geological Congress to the Urals in the summer of 1897 the writer was enabled to make a number of observations on the stages of dissection reached in various parts of these mountains. Photographs were taken from many summits and in various valleys and on grades of former river-courses, while sketches and profiles were made from these and many other points. Within the short limits of a month, however, only a very small area could be visited, even with the phenomenal facilities for travel in an undeveloped region given so freely by the Czar of Russia and all those who carried out his wishes; therefore the work done upon the dissection of this mountain region on the borders of Europe and Asia, and in the midst of a vast empire, can only be considered as a reconnaissance—a first attempt to solve the problem of the physiographic development of the Ural mountains.

In putting together, several months after the trip was made, the results obtained in various localities, there seems to be such an accordance in the general history of stream development that the writer is inclined to put forward rather strongly his impression in regard to the stages of stream dissection, gathered from two trips taken across the central portions of these mountains, and to offer it as a working hypothesis for future study of the development of the Urals.

Plan of Paper

The Russian work is first considered, and then the general features of the Urals are described—the planed uplands, the ridges rising to nearly the same elevations, the gentle arch formed by these summits, the summit-level plane descending gradually to the west until it merges into the upland levels of the great plain of central Russia. The upland level of Urals is shown to have in several places a rather steep fall-off to the Siberian plain, though in other places the plane of the summits merges into that of the great Tertiary deposits of northwestern Asia. The quartzite peaks and the other masses of more resistant rock which rise above the general summit level are described, and a general discussion is given of the valleys cut beneath the main planed surface of the Urals.

Planation in general is next taken up, and a distinction is sought between planed surfaces formed in four ways: First, those formed by rivers wearing down the land to baselevel; second, those produced by the attack of the sea on a stationary land-mass; third, those abrasion surfaces resulting from sea attack on a slowly sinking land-mass; fourth, those approximations to a uniform level due to more rapid wearing of higher summits.

Various parts of the Urals are then considered in detail, and the stages of dissection seen in each are compared and contrasted with one another. The grade-plains seen in various localities accord so well in relative breadth and elevation that the conclusion of the paper is that the most probable history of the dissection of the Ural mountains consists of three epicycles or divisions of the present cycle of erosion since the first uparching of the nearly completely planed mountains of the previous cycle.

Russian Work

The indefatigable labors of the Russian geologists, notably Karpinsky, Tschernychew, Pavlov, and Nikitin, have brought out the succession of strata and the geological structure of Russia in so many localities that it is now possible to understand the main structural features of the country and to make out much of the physiographic history of eastern Europe. The work of the Geological Survey of Russia was so far advanced in 1892 that a geological map of European Russian was published. It was slightly amended and added to in the edition of 1897, and this generalized statement gives one a graphic picture of the great geographic features of Russia, the scale of the map, 1 : 2,520,000, being just right to bring them out, though too small to show details. The topographic maps of Russia, on the scale of 1 : 420,000. are not so good as those of most other European countries, and they do not add much to the conception of land forms obtained from a study of the geologic maps.

The two great plains—that of central Russia and that which occupies nearly the whole of Siberia—stand out in marked contrast to the smaller surrounding areas of mountains. Central Russia is made up of nearly horizontal deposits from the Permian rocks down to those made by the recent rivers, as they baselevel the country by cutting their right banks and depositing the waste on their left banks. Many of these horizontal deposits are marine, though there have been several periods of land conditions, as, for example, the Triassic or the Recent. This whole region, as shown by its deposits, has oscillated back and forth near sealevel; now a little above and now a little below. The Siberian plain presents a vast expanse of Tertiary accumulation.

In contrast with this plain structure of central Russia are four areas of mountain structure, each cut off from the others by large bodies of water. Beginning on the north is the baseleveled area of the old mountains of Finland, separated from the Urals by the Arctic ocean. On the west come the Baltic sea and the Carpathian mountains, with their various outliers, including the old mountains west of Kiev, which are thoroughly planed down and now almost completely covered with Tertiary deposits. On the south are the Black sea and the Caucasus mountains, while on the east are the Caspian sea and the Ural mountains. The problems of the Caucasus, the Carpathians, and the old mountains of Finland are not discussed in this paper, attention being given only to the Urals and to those portions of the great central and Siberian plains which lie next the mountains.

The Russian field-workers have given much attention to the age of the deposits as determined by their contained fossils, to their superposition, and to their faulting; but practically no work has been done on the interpretation of the geologic history of the Urals from a study of the forms of the surface as controlled by the underlying structures. An occasional mention of a harder stratum as a ridge-maker is found in the "Guide to the excursions of the Seventh International Geological Congress," but no systematic use of form is made. The Russian geologists have not yet introduced the physiographic method of the Americans. This paper is written to point out the problems in the line of physiographic work needed in this region and to offer a suggestion as to what

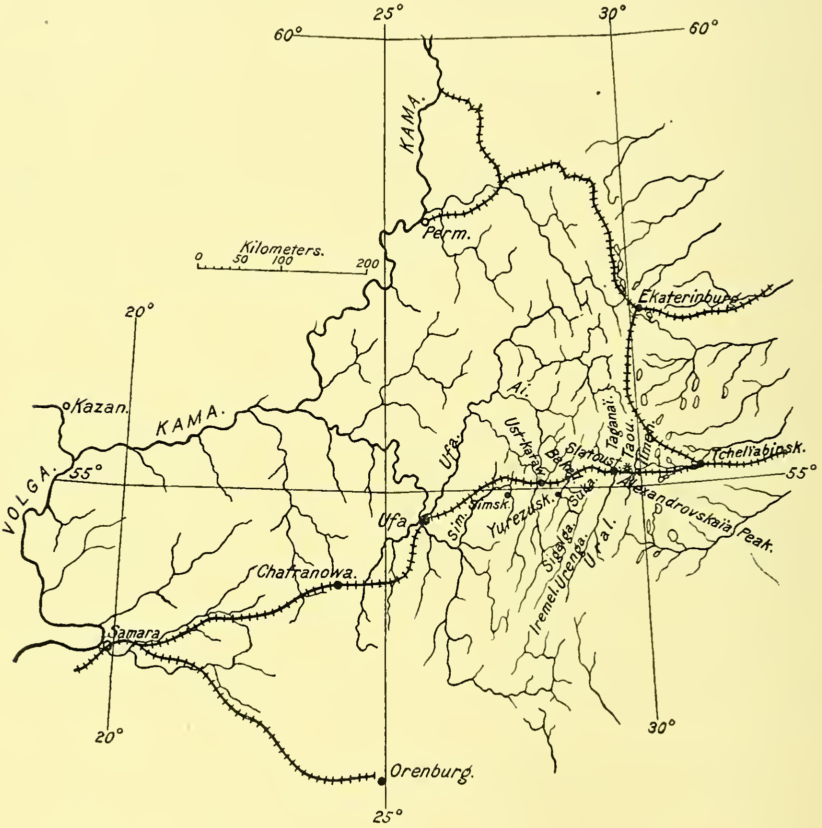

FIGURE 1.—*Drainage System of Ural Mountains.*

the probable result will be when the necessary field-work is done in Russia. It draws freely on the facts of structure as worked out by the Russian geologists.

Physiographic Description of the Region

CONTRAST BETWEEN CENTRAL RUSSIA AND THE URALS

From the poor topographic representation of the Ural mountains as given even on our best maps, one is led to think of them as rising sharply from the socalled steppes of Russia in some such form as the Rocky mountains loom up west of Denver when one approaches them across the Great plains in Colorado. This however is not the fact. The upland slopes on the plains are found to merge gradually into those of the mountains, so that when one leaves the Volga at Samara (see map, figure 1) to cross the mountains on the trans-Siberian route, he cannot say just when he has reached the Urals.

The country around Moscow does, indeed, contrast in a most pronounced way with that around Slatoust; the shallow troughs of the valleys, the gentle slopes, the flat uplands, the high state of cultivation, the large farmhouses, and the richer people are all seen on the plains, while in the dissected mountains are found deeper troughs, steeper slopes, upland ridges, a lower state of civilization. smaller houses, and poorer people. This marked difference, however, is really nothing more than the usual contrast between fertile plains, well graded and sufficiently watered, and dissected mountains. The boundary line between these two contrasting areas is not definite; each merges into the other. The horizontal strata of the plains become gently inclined, then tilted, and finally, in the body of the Urals, the rocks are folded and faulted.

CHAFRANOWA SECTION

On the road between Samara and Ufa we were given the opportunity to walk up to the divide between two tributaries of the Kama river near the little village of Chafranowa. Here the rocks are the Permian and Permo-Triassic or Tartarian series, and are slightly inclined, dipping a little to the west. These beds differ from each other in resistance, and so the harder ones stand out in bolder relief from the softer beds. At this village of Chafranowa there is a broad shelf, less than 50 meters below the general upland level, and this shelf is found to correspond to a certain division of the Devonian series (*c*); but when standing on this upland level and extending the same with the eye across to the west, north, and east, it was easy to perceive that this plain beneath the upland was also present in a good many localities where this division (*c*) of the Devonian was not to be found. The relation of this broad shelf to the upland and to the valleys cut beneath it is shown in figure 2. There are a few isolated summits rising a few meters above the upland in this region.

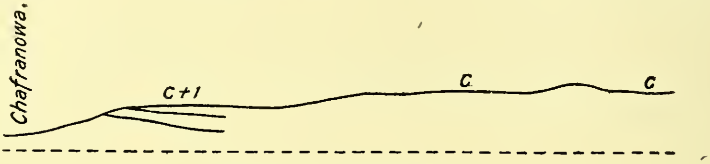

Figure 2.—*Chafranowa Section.*

The valleys in the present stage of dissection are about in adolescence.

THE RIDGES

After one has passed Ufa the character of the upland is changed from a broad, irregular, inter-stream upland to a succession of upland ridges, roughly parallel to the north and south axis of the Ural mountain folding. These ridges represent the harder or more resistant rocks which have longer withstood the subaerial degradation. The view from the summit of almost any of them discloses the fact that each rises to nearly the same elevation as those on either side, and that the departures from uniformity fall into two classes. The first variation from uniformity is a progressive increase in elevation in going toward the center of the Urals. A tangent surface touching these ridges would arch gently from a few hundred meters near Ufa to some 1,400 or 1,500 meters where it rested on the Urenga ridge near Slatoust. So gentle is this arch, however, that at any one point the ridges seem to be in the same plane.

The second class of variations are more irregular. Besides the valleys which are cut beneath this ridge plane there are a number of rock masses rising above the general level.

THE MONADNOCKS

In looking across the ridges from a number of different places it was seen that here and there a few points rise above the general summit level in any given locality. There are but few such rock masses along the western edge of the mountains near Ufa or Perm, but nearer the center of the mountain area these commanding peaks above the ridges were more and more frequently seen.

Taganaï is perhaps the best type of these higher summits. Three summits of resistant quartzite—Great, Little, and Middle Taganaï—rise above the weaker metamorphic schists, one quartzite bed having been faulted to produce these three peaks. From the foot of Great Taganaï there is a most extensive view of the Ural summits in all directions. The general accordance in elevation is nowhere better displayed; extending in all directions, summit after summit appears rising nearly to the same height and looking as if some mighty carpenter had planed away the crests of the mountain folds, leaving here and there a knotty place, which had been too tough for his plane to cut. These knots, or "monadnocks," as they are called in New England, from the typical form of mount Monadnock rising above the New England peneplain in southern New Hampshire, wherever studied by the writer in the Urals, whether from personal observation or from the testimony of the Russian geologists, are always of more resistant rock than the surrounding masses. The writer introduces the term "monadnock" at this point because it was largely from the form of these "knots" that he concluded that the Urals had been subaerially baseleveled.

Other very characteristic monadnocks are Alexandrovskaïa, Iremel, and several less striking summits on the Urenga ridge.

THE EASTERN SLOPE

The plain of the summits slopes down much more rapidly on the east than on the west from the Ural Taou or main chain of mountains. This is shown in figure 3, which gives a generalized section across the Urals, showing its typical forms. As shown in the section, there is a rather steep fall-off from the summit level to the planed surface of crystallines over which the Tertiary deposits of the Siberian plain lie on its eastern margin. This fall-off is not everywhere found, but in some places farther north the summit-level plane seems to dip down beneath the Tertiary deposits. Any theory for the planation of the Urals must take into account the presence of this fall-off in some places and its absence in others, and also include the planed crystallines with their old stream courses, now frequently occupied in part by lakes, as well as the very important deposit of Tertiary sediments farther east. Enough work has not been done to solve this problem, so that the discussion here presented is simply in the line of a tentative hypothesis.

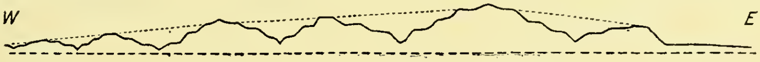

FIGURE 3.—*Diagrammatic Section of the Urals.*

The very natural suggestion has been made that the steep fall-off, as seen, for example, at Ilmen mountain, represents the attack of the Tertiary sea upon the Ural mountains, but there are some topographic forms which it is almost impossible to explain on this hypothesis. How were the valleys back of Ilmen mountain formed, and what became of the waste if the sea came up to this point? The absence of a sea-cliff in certain exposed places must be explained. Another difficulty is the surface of the granite, now covered with decomposed rock to greater or less depths and dotted with lakes. The lack of marine deposits in front of this fall-off makes its cliff origin seem doubtful, and the old form of the valleys and the decomposed rock in place point toward an old land surface.

If this low crystalline plain to the east of Ilmen mountain is an old land surface worn down, its relation to the summit-level plane of the Urals must be explained. It surely could not have been formed as the two plains stand today, and if the two were once continuous there must have been a fault along the eastern base of Ilmen mountain after the completion of the planation. If this hypothesis prove to be the correct one, then this Ilmen fall-off will be a very fine example of a fault scarp.

As bearing on the hypothesis of faulting after planation, it must be mentioned at this point that there were found by the present writer at several places on the slopes of Ilmen mountain benches which accord in elevation, as nearly as could be made out, with the grade-plains found in the central portions of the Urals, which were no doubt formed by streams after the uplifting of the nearly completely planed mountains.

If in the faulting there had been a slight tilt of the crystalline area toward the west, then the streams in this area would be hindered and in many places ponded. It should then follow that the lakes would be more abundant where the summit-level plane falls off more steeply. This is a question for further field study.

VALLEYS IN THE URALS

Beneath the summit-level plane the streams have carved their valleys, deeper in the central portion of the mountains where the planed land surface had been uplifted to the greater amount, and shallower where there had been but little up-arching, slower in more resistant strata, and faster in the weaker ones; but the striking feature of all the valleys is that they are not due to one simple uplift, but that they have been developed during a series of successive up-archings.

PLANATION

WORK OF RIVERS

The logical conclusion from a study of the weathering of rocks and the transportation of rock waste is that in any place the ultimate and necessary result of such degradation of its surface must be the reduction of the land to a nearly uniformly level plain close to sealevel. Powell, Dutton, and Gilbert were the first to clearly state this law of land baseleveling, after their study of the widening of the deeply cut canyons of the Colorado plateau. At Harvard Professor Davis has worked out with his students many of the characteristic features of land form connected with this process. The controlling plane beneath which the river can not cut is the level of the sea at the mouth of the river; the great plane of reference is therefore the ocean level, and lakes above sealevel or seas like the Caspian beneath sealevel are local baselevels which control the plains formed by the rivers emptying into them.

As long as there is a steeper grade at any point on the land than is just sufficient to allow the water to drain off some particles of land waste will be carried toward the sea down these slopes, and though the process will at last become very slow in operation, it must continue, if the land and water do not change their respective levels, until the land is worn down to a lowland, with the very gentlest of surface inequalities, but little above the level of the sea, forming almost a plain or peneplain.

When a region had been leveled by this method of planation there would generally remain as witnesses of the process masses of rock rising somewhat above the general level of the peneplain. These would consist of more resistant rock than that which immediately surrounded them, though the highest point may not necessarily be the hardest rock in the whole region, and such masses would not lie close to large river courses, nor be as numerous near the sea, which formed the baselevel, as at some distance from it. Other things being equal, one would expect to find the number of such masses of rock or monadnocks increasing in numbers the farther one went from the sea.

The stream courses on the surface of the subaerially planed area would be largely on the weaker rocks, while if the cycle of down-cutting had been made up of several divisions or epicycles, several periods of elevation following one another with long periods of wearing down between each uplift, this adjustment of stream to structures would be more perfect.*

The adjustment of drainage is the best method known of distinguishing this kind of planation from that performed by the sea. The lack of a cover of marine sediments is negative evidence in the same direction.

WORK OF THE SEA

The sea, aided by the atmospheric agencies, must also plane the land to form a nearly level plain, the plain of marine denudation of Ramsay.† This submarine platform is formed by the attack of the sea on the land, and if the land remains stationary the sea will cut into it strip by strip, depositing the greater portion of the detritus in a continental delta to seaward of this platform, but also covering the portions first formed with a thin cover of waste from the later abrasion. This cutting is limited in depth by the power of the waves to abrade the bottom, the limiting plane forming a local baselevel or *wave-base*‡ lying beneath the general baselevel formed by the surface of the sea.

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* W. M. Davis: Bull. Geol. Soc. Am., vol. 7, 1895, p. 395; London Geog. Jour., vol. v, 1895, p. 140.

† A. C. Ramsay: Denudation of South Wales. Mem. Geol. Sur. Great Britain, vol. i, 1846, p. 327; Phys. Geol. and Geog. of Great Britain, 5th ed., 1878, p. 497.

‡ Proc. Amer. Acad. of Arts and Sci., vol. xxxiv, 1898, p. 176.

The cover of unconformable sediments would be dissected by a system of consequent drainage when the land was elevated, and these consequent streams would not be adjusted to the structure of the underlying rocks, after the stripping off of the cover. Thus superposed streams would characterize such an area, in contrast to the adjusted drainage normal to a dissected peneplain.*

Harder rock masses would longer resist sea action, and therefore should be found as projecting tongues of land above the plane of the former wave-base, ideally a very different form from the typical monadnock.

A more exhaustive analysis of the expectable forms produced by these two planation agents would be helpful in studies of any given locality, such as that of the present paper. Either or both combined may have acted to form such surfaces as the summit-level plane of the Urals, the questions being which, or what portion by river and what by sea?

PLANATION ACCOMPANIED BY SLOW SINKING OF THE LAND

Von Richthofen † considers that the subaerial agencies would be unable to produce broad plains on dissimilar structures, and that the sea acting on a quiet land would in time exhaust its power of land attack. He therefore considers that all planed surfaces are produced by the abrasion of the waves on a successive series of shorelines in a slowly sinking region. The present writer would class these abrasion surfaces as a special form of sea-planed surfaces, perfectly possible and doubtless actual in certain regions.

One of the characteristics of this class of planed areas would be the large proportion of coarse conglomerate lying on the abraded surface. There would also be a decided inequality of the abraded surface, according to the hardness of the rocks, the more resistant kinds standing up out of the water in each epicycle of depression and becoming covered with the waste of the succeeding epicycles. The form of these masses would be very different from the subaerially carved monadnocks, and the planation being completed step by step would give a much less continuous plane than would result from river erosion.

PLANATION AT HIGH ELEVATIONS

Penck has described ‡ still another method of forming planed surfaces, which depends on the fact that wearing away is more rapid on a very high summit than on its lower neighbor. Thus there would be a tend-

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* W. M. Davis: Bull. Geol. Soc. Am., vol. 7, 1895–'96, p. 397.

† F. von Richthofen: China, 1882, vol. ii, chap. xiv: Führer für Forschungsreisende, Berlin, 1886, pp. 353–361.

‡ Albrecht Penck: Morphologie der Erdoberfläche, Stuttgart, 1894, vol. ii, pp. 161–165.

ency for high mountain summits to approach the same elevation in a given region after considerable lapse of time. It must be distinctly borne in mind, however, that the process would not tend to produce broad, level topped summits from very irregular masses. These high-level planed surfaces might be confused with an uplifted peneplain or submarine platform, which had been dissected to late maturity, so that there were no broad areas of undissected upland; but the details of form would in nearly all cases be different.

Too much care cannot be taken to see and carefully observe the topographic forms of dissected planed surfaces from the proper place to bring out the continuity of the former plain. One should stand on the edge of the yet undissected upland in order to look across ridge after ridge of the summits approaching this level. The grades formed by the later process of dissection here intersect the older and flatter grades of the peneplain or plain of marine denudation.

PLANATION IN THE URALS

EVIDENCE OF SUBAERIAL DEGRADATION

With a scheme such as that just described in mind, the writer studied the Urals, and he came to the conclusion that it was highly probable that the summit-level plane represents the action of subaerial degradation. The continuity of the uplands (plate 10, figure 1) and the accordance of elevation of neighboring ridges are too great to have been the result of abrasion of a continuously sinking land attacked from east and west, and for the same reason the plane can not be the result of high-level planation.

The forms of the residual hard masses rising above the plane, as far as seen, are typically the result of long continued land carving; in other words, they are monadnocks.

The longitudinal drainage of the western slope of the Urals, particularly that of the Kama and Ufa rivers and their branches, passing through a few transverse courses, conforms so thoroughly to the structure that it is thought to have originated from a system of drainage already well adjusted when the subaerial planation of the mountains was completed and the lowlands up-arched. It does not seem probable that such perfect adjustment could result from streams consequent on a cover overlying the planed surface. Marine planation would then be out of the question, and subaerial planation is the best working hypothesis for future studies.

DISSECTION AT UFA

Ufa, or Oufa according to the French spelling, lies at the junction of the Sim and Ufa rivers, in the region where the Permian rocks are changing from the horizontal to the folded structure in that transition field between plains and mountains. The section in this region (figure 4) is therefore of great importance in connecting the grade-plains in the mountains with the uplands of the plains. The party was not in this region long enough to allow any excursions back on the uplands, but from what the writer saw he is inclined to group the upland level (u, of figure 4) of this region with the first grade-plain formed beneath the upland in other sections (see $s+1$, $k+1$, etcetera, of figures 5 and 6). In these sections the writer has given a different letter to each; in all cases representing the upland by the simple letter and giving the successive grade-plains formed beneath the upland the same letter, with $+1$, $+2$, etcetera, added.

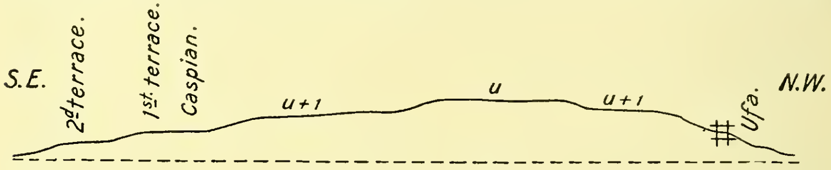

FIGURE 4.—*Section at Ufa.*

There are two aggradation plains above the present river channels in this region, the upper terrace representing the late Caspian expansion and the lower an alluvial terrace, formed since the Caspian stage.

GRADE-PLAINS NEAR SIMSK

Along the Sim river the writer went up several times on the grade-plains above the river, and it appears quite possible that the upland at Simsk (s, of figure 5) and the grade-plain next beneath it ($s+1$) gradually approach each other and meet somewhere near Ufa. This would mean that the first up-arching of the Urals, after the long period of planation, did not extend farther west than the area between Simsk and Ufa. The uplands in this whole region should be carefully studied to test this suggestion.

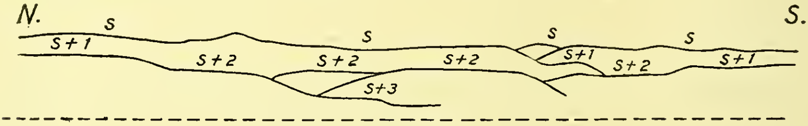

FIGURE 5.—*Simsk Grade-plains.*

At Simsk were two well marked dissection grades between the upland and the present river grade (figure 5). The estimated relations in elevation of these plains is as follows: $s+2$ is 80 to 100 meters above the

Figure 1—Ural Taou Ridge
Looking south from Alexandrovskaïa

Figure 2—Grade Plain b + 1
West of Suka mountains

Figure 3—Ural Taou
From west of Slatoust

Figure 4—Ural Taou and Alexandrovskaïa Peak
View taken from Urenga

VIEWS IN THE URALS

valley floor; $s+1$ is some 50 meters above $s+2$, and s is not over 100 meters above $s+1$.

UST-KATAW DISSECTION

Although the rocks are changing, the relative elevation and breadth of the series of grade-plains seen at Simsk are continued eastward. At Ust-Kataw the same two dissection planes are found between this upland and the river bed (figure 6).

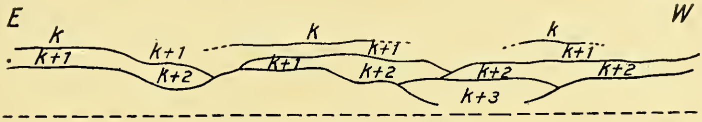

Figure 6.—*Profile near Ust-Kataw.*

YUREZUSK PLAIN

On the road to Bakal we passed the little village of Yurezusk, where there is a broad expanse of the plain formed in the second epicycle of dissection following the long cycle of planation. This is unusually broad with reference to the preceding epicycle (figure 7), and the form suggests that the rocks here have been easily worn away. The upland level on Sigalga mountain in this region is 1,400 meters above sealevel.

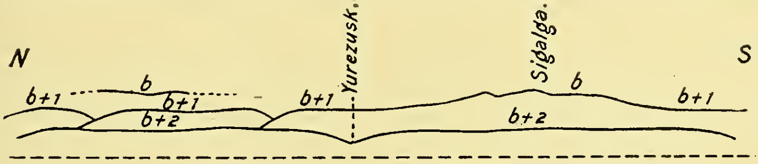

Figure 7.—*Yurezusk Grade-plain.*

SUKA MOUNTAIN

One of the broadest plains representing river grades cut below the upland is seen west of Suka mountain (plate 10, figure 2). This view shows the accordance in elevation of the summits ($b+1$, of figure 7), which are several hundred meters above the lower level grade-plains ($b+2$), and are also some 200 meters below the summit-level plane in this region. The broad tops of Suka and the surrounding ridges rise to some 1,200 meters above the sea.

TAGANAÏ SECTIONS NEAR SLATOUST

In the region around Slatoust the distinction between these three plains is most clear and decisive (figure 8). There are several places where all three occur together and always with the same relative elevation and breadth; therefore this point is peculiarly favorable for beginning a thorough study of the stages of dissection of the Urals.

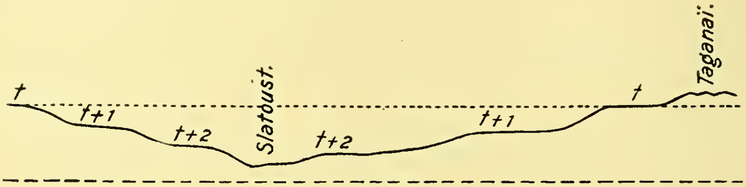

FIGURE 8.—*Taganaï Section.*

A photograph was taken west of Slatoust, looking toward Ural Taou (plate 10, figure 3). This view was taken a few meters above the level of the grade-plain ($t + 1$, of figure 8), in order to show the successive ridges rising to accordant elevations.

A second photograph (plate 10, figure 4) was taken from the foot of Urenga mountain a little above the grade-plain ($t + 2$). This shows a lake on $t + 2$ (of figure 8), a glimpse of $t + 1$, the summit of the Ural Taou forming t, and Alexandrovskaïa peak which is a typical monadnock.

DISSECTION WEST OF ILMEN MOUNTAIN

The divide in the Urals passed, the same grade-plains are seen between Alexandrovskaïa and Ilmen mountains; the same relations hold also at several places farther north on the east slope. The steep fall-off has been mentioned, and a suggestion made to account for it.

CONCLUSIONS

Although not all the facts of topographic form are explained by his tentative outline of the history of the Urals, still there are so many facts which support it that the writer advances with some confidence the following working hypothesis:

First, a long period of subaerial planation, leaving a few monadnocks, aided on the margin by marine planation, the limits of which are not as yet worked out; second, an up-arching of the Urals, the axis of the movement and the line of greatest uplift being a little east of the middle of the mountains; third, a long period of stream dissection forming broad plains on the less resistant rocks; fourth, a second up-arching, generally of less amount than the first, with the axis (in the region studied) not far from the first; fifth, a second period of stream cutting, not so long as the first; sixth, a third up-arching; seventh, the cutting of the present stream grades, during which time occurred the Caspian expansion.

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OUR SOCIETY

ANNUAL ADDRESS BY THE PRESIDENT, J. J. STEVENSON

(Read before the Society December 28, 1898)

CONTENTS

Early Investigations

Several travelers of the eighteenth century, among them, especially, Guettard, Alexander, and Schoepf, gave more or less important information respecting the geological structure and mineral resources of our country; but geological work, properly so called, began only with Maclure's studies in 1806. Born in Scotland, Maclure came to this country in early youth, and, embarking in business, acquired a fortune long before reaching middle age. He returned to Europe to spend several years in the study of natural science, but came again to America in 1806 to take up his geological work, which continued until 1808.

The publication of his results, presented to the American Philosophical Society on January 20, 1809, led others to make studies, and soon afterwards there appeared numerous papers dealing with geological subjects. Professor Samuel L. Mitchell, a devoted follower of Werner, infused much of his enthusiasm into a group of youthful students in New York and induced Professor Archibald Bruce to establish the American Journal of Mineralogy, which, beginning in 1810, reached its fourth and last number in February, 1814. Though small and short-lived, this journal served a useful purpose: it contained good papers by Ackerly, Gibbs, Godon, Mitchell, Silliman, and others; it did much to nurse the scientific tendency which led to founding the New York Lyceum of Natural History in 1817, and some have thought that it aided in like manner the founding of the Philadelphia Academy in 1812. Bruce's Journal was succeeded in 1818 by Silliman's American Journal of Science, which from the beginning exerted a notable influence on the development of geological thought and work in our country.

By 1820 students of geology had become so numerous that the American Geological Society was organized in New Haven, Connecticut, where meetings were held certainly until the end of 1828.* The last survivor of this society died in New Haven only a few weeks before the formal organization of our Society, in 1888. The prominent men in 1820 were Ackerly, Bruce, Cornelius, Cleaveland, the two Danas, Dewey, Eaton, Gibbs, Godon, Hitchcock, Maclure, Mitchell, Rafinesque, Schoolcraft, Silliman, and Steinhauer, but there were some young men who began to publish within two or three years afterwards and who were destined to occupy prominent places in geological literature; of these Emmons, Harlan, Lea, Morton, Troost, and Vanuxem were already engaged in investigation.

Before another decade had passed, there were groups of geologists in New England, New York, and Pennsylvania; while Olmstead and Vanuxem had made preliminary surveys in North Carolina and South Carolina, Troost had begun the survey of Tennessee, and Hitchcock that of Massachusetts.

In 1832 the Pennsylvania geologists, feeling much in need of an official survey of their state, organized the Geological Society of Pennsylvania to arouse public interest, and so to bring about the survey. The volume of publications contains papers which attack geologic and economic problems of the first order. The investigations were not confined to Pennsylvania, but committees were appointed to examine important matters in other states that the worth of geological work might be made obvious. Beyond doubt, the efforts of this society had much to do with securing the first geological survey of Pennsylvania, though no member of the society was appointed on the staff.

It is the fashion now and then to laugh at these old papers. True enough, in the light of our present knowledge, many of the statements respecting Appalachian structure are absurd, but they were made by men who without state aid, without instruments, and without maps laid a foundation upon which the keen-eyed men of the first Pennsylvania survey built that superstructure which endured close reëxamination by

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*I am indebted to Professor H. S. Williams for information respecting this society.

the second survey and proved the honesty and ability with which the work had been performed.

The Association of American Geologists

But geology was becoming too broad in scope and its workers too numerous to be embraced in a merely local society, even though the list of correspondents was as large as that of the active members. The work in Massachusetts was approaching completion; that in New Jersey had been completed; the surveys of Maine, Connecticut, New York, Pennsylvania, Maryland, Delaware, Virginia, Ohio, Michigan, and Indiana had been begun, and before 1840 New Brunswick, Rhode Island, and Kentucky were added to the list. Several of these surveys had large corps of workers pushing their studies with all the enthusiasm of a new calling. In the Appalachian region of Massachusetts, New York, Pennsylvania, and Virginia serious problems were encountered, which could not be solved within the compass of a single state. A right understanding of the work done in one state was necessary to a right understanding of the work done in the adjoining state. Correspondence proved a failure; incidental or casual talks led to misunderstandings; systematic conference was necessary, with generous contribution by each of his knowledge to the other.

On April 2, 1840, as the result of a conference held at Albany in 1839, eighteen geologists met at the Franklin Institute, Philadelphia, and organized the Association of American Geologists, with Professor Edward Hitchcock as the first chairman. Among them were the state geologist of Massachusetts, six geologists of the New York survey, six of the Pennsylvania survey, two of the Michigan, and three not connected with any public work. Mr Martin H. Boye is the only survivor of the eighteen. The succeeding meetings in Philadelphia and Boston were attended by many geologists, of whom only Boye, O. P. Hubbard, and J. P. Lesley remain. A volume published in 1843 contains several papers which made a deep impress on American geology. In it are the five great memoirs on Appalachian conditions by the Rogers brothers Hall's noteworthy discussion of the Mississippi basin section; Hitchcock's elaborate discussion of the drift, as well as numerous contributions by other members.

Professor Hall said on one occasion that the inspiriting effect of these meetings could not be overestimated. As one of the youngest members, he was impressed by the mental power of those great men, all untrained in geology except Taylor, whose instruction under William Smith proved advantageous in many ways, but very disadvantageous in others, as it had provided him with a generous stock of well set opinions. Though wholly self-taught, working in a country sparsely settled, without barometers, without railroad cuts, oil borings, mine shafts, or any of the helps so necessary for us, those men had elaborated systems, had made broad generalizations, had learned much respecting the succession of life, and had discovered the keys which in later years were to open mysterious recesses in European geology.

The American Association for the Advancement of Science

But the geologists were not permitted to flock by themselves. The advantages of contact were so manifest that the naturalists asserted their claims to relationship with sufficient energy to secure admission in 1841, and the name Association of American Geologists and Naturalists appeared in the constitution adopted at the 1842 meeting. The number of scientific men was still comparatively small, and in most of the colleges the several branches of natural science were embraced in one chair, so that there were many professors who could lay claim to the title of geologist, physicist, naturalist, or chemist, as they pleased. Men of this type, as well as physicists, chemists, and mathematicians, constantly urged the propriety of broadening the scope of the association so as to admit workers in all branches of science.

In 1842 the first series of surveys practically came to an end, and the geologists were scattered, many of the younger men being compelled to enter other callings. The Association held its meetings regularly, but its strength diminished, and in 1848 it yielded to the outside pressure, becoming merged into the American Association for the Advancement of Science, which threw its doors wide open to all entertaining an interest in any branch of science. The first meeting of the new organization had a roll of 461 members.

Comparatively little was done in geological work between 1842 and the close of the civil war. Professor Hall maintained the New York survey, after a fashion, but at very considerable pecuniary cost to himself; surveys were carried on in a number of states, but except in Illinois and California they were mostly reconnaissances by small corps; the annual appropriations in several instances were little more than enough to pay traveling expenses, so that the work and the reports were practically gifts to the states; the federal government sent topographic expeditions into the western country, most of them accompanied by a surgeon who had more or less knowledge of geology. Under such conditions the number of geologists did not increase, and when the American Association was divided into sections, in 1875, the geologists and naturalists became, not Section A, but Section B.

Development of geological Work after the Civil War

The rapid development of the country's internal resources during the war and the attendant growth in manufacturing interests made necessary increased efficiency in scientific training, and enormous gifts were made to our leading institutions for that purpose. The importance of geological knowledge had become very evident during the development of iron, coal, and oil resources, and the geologist found himself elevated suddenly from a place surrounded by suspicion to a post of honor. As an outgrowth of the restless activity due to the war came anxiety to learn more accurately the resources of our western domain beyond the hundredth meridian. The War Department, through its engineer corps, organized the Fortieth Parallel Survey, in charge of Clarence King, and two years afterward authorized Lieutenant (now Major) George M. Wheeler to undertake what afterward became the United States Geographical Surveys West of the Hundredth Meridian. Mr King's survey was primarily for geological work, that of Lieutenant Wheeler primarily for topographical work, but each in its own field did all the work, geological or topographical, necessary to the accomplishment of the allotted task. The Interior Department had charge of Dr F. V. Hayden's surveys, beginning in 1867, as well as of the work prosecuted by Major J. W. Powell after 1870. The consolidation in 1879 of all the organizations then existing into the United States Geological Survey put an end to useless rivalries and made possible the formation and execution of broad plans requiring a high grade of preparation in those engaged on the work.

While these surveys were advancing in the far west, great activity prevailed in the older area. Within a decade after the war ended state surveys were undertaken in New Hampshire, New Jersey, Pennsylvania, Ohio, Indiana, Kentucky, Michigan, Wisconsin, Minnesota, Iowa, Missouri, and other states, while the Canadian survey, which had gone on uninterruptedly from the early forties, was made more extended in character. Several of the state surveys, being well supported by generous appropriations, employed large corps of assistants, paid and volunteer, and were prosecuted with great energy. Under these conditions Section E, that of Geology and Geography, grew rapidly and soon became one of the strongest in the American Association for the Advancement of Science.

The conditions which rendered imperative an association of geologists in 1840 were the present conditions in 1880, but more oppressive. The problems of 1840 were chiefly those of a narrow strip within the Appalachian area; those of 1880 concerned the whole continent. Geologists were increasing in numbers, but opportunities for making personal acquaintance were few. Meetings of societies in midsummer could be attended only by those who were not connected with official surveys or were detached for office work. Workers were gathering into little groups on geographical lines and there was danger that our geology would become provincialized. Members of one group regarded those of another with a feeling not altogether unrelated to suspicion; letter-writing took the place of personal communication, with too often the not unusual result of complete misunderstanding, with the attendant personal irritation or worse.

The Geological Society of America

In 1881 the tension was such that several geologists connected with official surveys urged the formation of a geological society to bring about closer bonds among geologists, and they succeeded at the meeting of the American Association in securing the appointment of a committee to consider the matter. The geologists of the country were consulted and a report showing that the consensus of the replies favored the organization of such a society was presented in 1882, as well as in 1883, but without any result. The Association's committee on the International Geological Congress considered the question in 1887 and announced approval. Professors N. H. Winchell and C. H. Hitchcock, as chairman and secretary of the 1881 committee, issued a call asking geologists to assemble at Cleveland, Ohio, on August 14, 1888, to form a geological society.

A large number of geologists and other members of Section E assembled on the afternoon of that day. Professor Alexander Winchell presided and Dr Julius Pohlman was secretary. An earnest discussion respecting the type of society to be founded occupied most of the afternoon. The plan suggested in the call looked only to an expansion of Section E of the American Association by holding meetings at times better suited than summer to the convenience of geologists. A difference of opinion, however, quickly developed, for some knew that no such expedient would suffice, because the conditions called for something more definite. Loyalty to the American Association, which for forty years had been the bond between scientific men, held many back from an extreme position; yet every one recognized that little injury could come to the Association, as at best only a few geologists could attend summer meetings. In any event, it was clear that the interests of geology required the formation of a society with severe restrictions upon membership and with publications which would be a credit to American science. A compromise prevailed, whereby the original members entitled to take part in organization must be members of Section E of the American Association, and that all members of Section E might enroll prior to the first meeting, if they so desired. This last provision caused not a little anxiety, as membership in any section of the Association predicates nothing more than a friendly feeling for science—whatever that may mean.

A committee* was appointed to prepare a plan of organization with a provisional constitution. The committee's report on the morning of the fifteenth provoked debate, as the provisional constitution placed a positive limit upon the membership by permitting after the organization only working geologists and teachers of geology to become members and by requiring a three-fourths vote for election. The organization was to be effected when the list of original members contained one hundred names. The provisional constitution, with a few unimportant amendments, was agreed to unanimously, and the committee was continued as a committee of organization. The details of arrangements were placed in the hands of Professors A. Winchell and Stevenson.

Happily the high dues and a general belief that no society could be formed on the proposed basis kept the list of Original Fellows from being swollen by those whose relation to geology began and ended with attendance upon the American Association's meetings. The committee was enabled from the very outset practically to choose the men who should make the Society. The required number having been obtained by the 1st of December, a meeting was held at Ithaca, New York, on December 27, 1888. Only thirteen were present, but ballots of preference had been received from seventy-two Fellows, in accordance with which the organization was completed by the election of—

President	James Hall.
Vice-Presidents	James D. Dana. Alexander Winchell.
Secretary	John J. Stevenson.
Treasurer	Henry S. Williams.
Councilors	John S. Newberry. John W. Powell. Charles H. Hitchcock.

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*This committee consisted of Alexander Winchell, J. J. Stevenson, C. H. Hitchcock, John R. Procter, and Edward Orton.

The matter of publication was discussed at great length, but no definite decision could be reached, and a committee was appointed to consider the whole question, with instructions to present a report at the summer meeting. Another committee was appointed to prepare a permanent constitution, to be presented at the next meeting.

The Advisory Committee on Publication, another name for Professor W J McGee, made an elaborate investigation of the whole question of publication, and in August, at Toronto, presented the report, accompanied by a printed example of the form recommended. This report was adopted, and at the close of the following meeting Professor McGee was chosen as the first Editor, that the recommendations might be carried out faithfully. Our Bulletin, which marked a new stage in scientific publications, owes its excellence of form and accuracy of method to his indefatigable persistence. His determination to secure exactness in all respects proved not wholly satisfactory to many of us, but before he demitted his charge the justice of his requirements was conceded on all sides. The discipline to which the Fellows of this Society were subjected by the first Editor has served its purpose, and editors of other scientific publications have found their labors lightened and their hands strengthened in efforts to produce similar reforms elsewhere. His mantle fell upon Mr J. Stanley-Brown, who inherited a double portion of his spirit, so that the high standard of the Bulletin has been maintained without abatement.

Fears and misgivings abounded when it was discovered that this Society was a success from the start. The American Association for the Advancement of Science had been the one society for so many years that attempts at differentiation seemed to be efforts to cut away the pillars of scientific order; but the fears were merely nightmare; our Society has proved itself an efficient ally of the association.

Our net membership at the close of the first year was 187. The new constitution placed severer restrictions on membership by requiring a nine-tenths vote for election, the ballot being by correspondence and shared in by all the Fellows. This has kept the number within reasonable limits, and we now have 237 Fellows, our roll including almost all of those who by strict construction of our constitution are qualified for membership.

Owing to the rigid administration of our affairs by Professor Fairchild and Dr White, who have piloted us for eight years, our financial condition is satisfactory and the income from the permanent fund now goes far toward covering the cost of administration.

Throughout, the Society has held closely to investigation. The recondite problems—those of little interest to many, of no interest to most—

are those which have held the attention of our Fellows—work in pure rather than in applied science; there has been no trenching upon the field of the mining engineer. As a storehouse of fact and of broad, just generalization, the volumes of our Bulletin are excelled by those of no similar publication.

We close our first decade justly gratified by success and full of hope for the future. Some of those who led us and gave us reputation at the beginning are no longer with us. Hall, Dana, and Winchell, the first three Presidents, passed away in reverse order; Cope, Cook, Sterry-Hunt, Newberry, and a few others have gone from us, but the Society retains its membership with changes unusually small, showing no ordinary degree of physical force and *esprit du corps* on the part of its Fellows. As we look back, we recognize how far this Society has been of service to us as men. In not a few instances misunderstandings have been removed and coldness or suspicion has been replaced by personal friendship. American geologists are no longer a disorderly lot of irregulars marching in awkward squads, but form a reasonably compact body, though as individuals they may owe allegiance to Canada, the United States, Mexico, or Brazil. Every one of us has felt the inspiriting influence of personal contact.

Relation of geological Work to the Public Welfare

But our Society has to do with the world outside of itself and outside of its immediate line of thought. It must have more to do with that world in the future if the outcome for science is to be what it should be, for the time is approaching rapidly when we must seek large sums for aid in prosecuting our work. To retain the respect of the community and to retain influence for good, we must be able to justify the existence of a society devoted to investigation as distinguished from application. The question, "Cui bono?" will be asked, and the answer cannot be avoided.

This is a utilitarian age—not utilitarian as understood by those who bemoan the decay of esthetic taste, or of those who feel that in the passing of Aristotle and Seneca there has come the loss of intellectual refinement, or of those others who bewail the degeneracy of a generation which has not produced a Kant, a Newton, an Aristotle, a Laplace, a Humboldt, or an Agassiz—all regarding the decadence as due to the degrading influence of material development and overpowering commercial interests.

These pessimists stand at a poor point of view, where the angle of vision is narrowed by many lateral projections. One may say without fear of successful contradiction that, in so far as actual knowledge is concerned, students of our day receiving graduate degrees in the more advanced universities stand on a somewhat higher plane, each in his own group, than did the celebrated men just named. The student now reaches beyond where they ended, and still is at only the threshold, for in most instances years of labor are required of him before he can receive recognition as an efficient co-worker. Men towering far above their fellows and covering the whole field of knowledge will never be known again. Kant, Newton, and Humboldt stand out from their fellows as sharply as light-houses on a level shore; but there are many Kants, Newtons, and Humboldts today. Prior to the last seventy-five years the field of actual knowledge was insignificant, and a man possessing large powers of observation grasped the whole. Seventy-five years ago one man was expected to cover the whole field of natural science in an American college. Should any man pretend today to possess such ability he would expose himself to ridicule.

It may be true that this century has given to the world no great philosopher—that is, no great philosopher after the old pattern—but one must not forget that philosophy has to face a difficulty which was unknown in the last century. The unrestrained soaring of philosophers into the far-away regions of mysticism is no longer possible, for facts abound and the knowledge which is abroad in the land must be considered in any well constructed system. Some have maintained, if not in direct statement, certainly in effect, that study of material things unfits one for metaphysical investigation. Undoubtedly it would hamper him in some kinds of metaphysical research, as it would fetter him with a respect for actualities, but it would fit him well for other kinds. Aristotle, Kant, and, in our own time, McCosh and Spencer attained to high position as philosophers, and in each case possessed remarkable knowledge in respect to material things.

The assertion of lost intellectual refinement and of depraved esthetic taste is but the wail for an abandoned cult; it is but a variation of the familiar song which has sounded down the generations. The world was going to destruction when copper ceased to be legal tender, as well as when Latin ceased to be the language of university lectures; art disappeared when men ceased idealizing and began to paint nature as it is; religion was doomed to contempt when the Bible was translated into the vulgar tongue, and the pillars of the earth were removed when the American republic was established.

But in a proper sense this is a utilitarian age. Everywhere the feeling grows that the earth is for man—for the rich and for the poor alike; that those things only are good which benefit mankind by elevating the mental or physical conditions. Until the present century the importance of the purely intellectual side of man was overestimated by scholars, and matters connected with his material side were contemned. With our century the reaction was too great, for even educated men sneered at abstract studies as absurdities, while they thought material things alone worthy of investigation; but the balance is steadying itself, and at each oscillation the index approaches more closely to the mean between the so-called intellectual and material sides. Even devotees of pure science no longer regard devotees of applied science as rather distant relations who have taken up with low-born associates.

There appears at first glance to be very little connection between great manufacturing interests on one hand and stone-pecking at the roadside or the counting of striæ on a fossil on the other; yet a geologist rarely publishes the results of a vacation study without enabling somebody else to improve his condition. About twenty years ago one of our Fellows began to give the results of reconnaissance studies made during vacations. These concerned certain fault lines, and the notes included studies upon coal-beds and other matters of economic interest involved in the faults. The coal-beds were all bought up, railroads were constructed, mines were operated, towns were built, a great population was supplied with work at good wages, and many men were enriched. According to the latest information, no one has offered to reimburse the geologist his expenses, nor has any paper in the whole region suggested that the geologist had anything to do with bringing about the development.

Geological work in this, as in other lands, was originally vacation work, but eventually the investigations became too extensive and the problems too broad for the usually limited means of the students. Meanwhile it became manifest, as in the case just referred to, that important economic results were almost certain to follow publication of matters discovered by geologists, so that men interested in economics were ready to assist in securing state aid to advance geological work. As one of our Fellows remarked the other day, economic geology has been the breastwork behind which scientific geology has been developed by state aid.

Ducatel's reconnaissance proved the importance of Maryland's coal field, and the survey was ordered; the Pennsylvania Geological Society discussed coal-fields until the legislature gave the state a survey; the geologists of New York promised to settle finally the question of the occurrence of coal within the state, and so in many other states.

The United States Geological Survey had a somewhat different origin, for the economic side did not attain importance until a late period. Soon after the annexation of California the necessity for railroad communication with the Pacific became apparent, and the Congress ordered exploration of several lines across the Rocky Mountain region. At that time, the early "fifties," the perplexities of American geologists had reached a maximum. Most of the old state surveys had come to a close—rich in economic results and still richer in problems to be solved only by elaborate investigation too extended and too costly for those days. The observations made by Wislezenus and army officers in New Mexico, by Fremont and Stansbury farther north in the Rocky Mountain and Plateau regions, as well as by Culbertson and Norwood in the Dakota country, had stirred the curiosity and awakened the interest of geologists everywhere. Strong pressure was brought to bear on the Secretary of War for appointment of geologists to positions on the several parties. The efforts were successful and the appointments were made, though in most instances the geologists were physicians and appointed as acting surgeons in the army. This was an important advance in scientific work, for almost without exception exploring parties under the War Department from that time were accompanied by naturalists. The civil war brought the western work to a close; but when peace returned it was taken up again, and geology was recognized as a necessary part of it, until at last the fragmentary works were placed in one organization and the survey established as it now exists.

In all of the later geological surveys the element of economics entered more largely into consideration, and was emphasized in the legislative enactments. Men recognized that geological investigation had led to the discovery of laws most important from the economic standpoint, and they were anxious to have the knowledge utilized in a broad way.

Looking over the history of the old surveys, one sees clearly that their origin was due solely to a desire for solution of problems in pure science. The credit for the economic outcome of the scientific work is due to the geologist alone, to whom the appropriations were given, practically as a gift. The legislators soothed their consciences by lofty speeches respecting the duty of the commonwealth to foster the study of nature, but they generally had an aside to be utilized as a justification before their constituents, "especially when there is a very reasonable chance that something of value will be discovered to the advantage of our commonwealth."

Economic Results of official Surveys

The New York survey had for its possible outcome the determination of the coal area. The work was completed with great exactness, for it proved that the state contains no coal area whatever. Though only negative in results for the state, this survey has proved of incalculable service to the country at large, for it first elaborated the lower and middle Paleozoic section. The scientific work continued along the biological line defined accurately the vertical limits of fossils and provided means for removal of difficulties where the succession is incomplete, and for tentative correlation in widely separated localities, an apparatus whose usefulness cannot be overestimated from an economic standpoint.

If the man who makes two blades of grass grow where only one grew before be a public benefactor, what shall be said of the geologist who turns a desert into a garden? This was done by the first survey of New Jersey, which differentiated and mapped the marls of that state, giving a complete discussion of their nature and value. Great areas of the "white sand barrens" have been converted, not into mere farm lands, but into richly productive garden spots. In later years the second survey, now almost forty years old, did, as it is still doing, admirable work along the same lines. The study of the structural geology gave a clue to the causes of restrained drainage, and in not a few instances showed that relief from malaria could be obtained with unsuspected ease, and that many miles of noxious swamps could be converted into lands well fitted for residence.

The first survey of Pennsylvania was purely scientific in inception and execution; economic questions had little of interest for its head, and in the work their place was very subordinate to those in pure science; yet the outcome was inevitable. The study of the Appalachian folds and the discovery of the steeper northwesterly dip revealed the structure of the anthracite region and made it possible to determine the relations of the anthracite beds; the vast extent of the bituminous area and the importance of the Pittsburg coal-bed were ascertained during the search for facts to explain the origin of the Coal Measures; the ores of the central part of the state were studied with rigorous attention to detail, that the problem of their origin might be solved; but these and other scientific studies brought out a mass of facts which were seen at once to possess immense importance, and the reports were published broadcast. New industries were established; old ones previously uncertain became certain and developed prodigiously; the coal and iron interests moved at once to the front, so that within two or three years after the survey ended "tariff" became the burning political question throughout the state. The results of the second survey were even more remarkable in their influence upon the development of the commonwealth and the increased comfort of the population.

Among the earliest results of the first survey of Michigan was the determination of the value of the salt lands and the announcement of iron ore in the upper peninsula. The successors to this survey, under the United States supervision, made studies of numerous localities and determined the excellence of the ores. Unquestionably the importance of the deposit became known to capitalists very largely through the reports of this survey, though at that time economic geology had no charms for its head. Much of the enormous development of the Lake Superior iron region was due to the influence of the later survey between 1869 and 1873.

The first Ohio survey, made sixty years ago, was at greater disadvantage than the Pennsylvania survey, yet in the first year the coal area was defined, and during the second the geologists determined the distribution of the several limestones and sandstones which, as building stones, have become so important. The second survey was made effective at once by the tracing and identification of the Hocking Valley coal, which brought into the state a vast amount of new capital and changed the face of a whole district. The third survey determined the distribution of oil and gas, the relations of the coal-beds, and the characteristics of the clay deposits in such fashion as to remake the manufacturing interests of the state.

The Mesabi and Vermillion ranges of Minnesota contain deposits of iron ore which for the present at least appear to be even more important than those of northern Michigan. Almost fifty years ago J. G. Norwood, while studying the easterly end of the region, discovered the Mesabi ores. A few years later Whittlesey, after a detailed examination farther west, predicted the discovery of similar ores—a discovery actually made in 1866 by Eames, who was then state geologist and engaged in studying the Vermillion range. Though not utilized at once, these announcements were not forgotten, and systematic exploration was begun in 1875, when the need of high-grade ores at low prices made necessary the opening of new areas. Almost at once the then recently organized state geological survey determined the extent of the ore-bearing region, differentiated the deposits, and removed erroneous impressions respecting the extent and distribution of the ores. The effect of these discussions and of the positive fixing of areas has been to increase development and to cheapen ores of the best quality so far that Bessemer steel can be manufactured more cheaply in the United States than elsewhere, in spite of the fact that wages are still higher, not simply numerically, but in purchasing power, than in any other iron-producing country. An examination of the reports which have brought about this result compels one to say that anxiety for economic results does not appear to have been the impelling motive during the work. There were perplexing geological problems to be worked out and the solutions could be discovered only by the most painstaking work. This investigation led to the economic results.

The United States Geological Survey retained its original character for a number of years, the studies being devoted almost wholly to pure science. There were those who looked on the elaborate petrographical work as merely an elaborate waste of public funds; who, like the member of the Ohio legislature, regarded fossils only as "clams and salamanders" and considered the diagrams of sections as merely bewildering humbug, while they asserted that attention ought to be given to other matters, which, however, they were not always ready to designate. But the outcome of these studies was the inevitable. Petrography has its applications now in the investigation of building stones, and it has proved of service in aiding to determine the source of precious metals at more than one important locality. The determination of fossils has led to proper definition of the great coal horizons of the Upper Cretaceous; the close study of stratigraphical relations made possible a wide development of artesian-well systems in the Dakotas, just as similar work in England led to the same practical result, while the study of climatic and structural conditions was brought to bear on the great problem of our arid lands with no mean results.

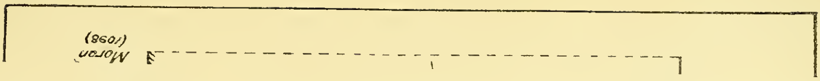
But these illustrations must suffice, not because they exhaust the material, for every official survey on the continent affords illustrations, but because this is an address, not a history, and already the allotted time has been exceeded.

It is the old story—the same in geology as in other branches. The kind of work for which this Society stands lies more closely to the welfare of the community than is supposed even by men in high position and of far more than average intelligence. This work is responsible in large part for the industrial progress of our continent, which we must regard, in spite of protests from those who lament the dominance of commercialism, as the force which has made possible our great advance in physical comfort as well as the equally great advance in literary culture and esthetic taste. Coal, iron, and oil, chief among our products, have been so much the objects of minute study by closet investigators that improvement in processes of manufacture has not been a growth, but rather a series of leaps.

We give all honor to applied science, yet we cannot forget that it is but a follower of pure science. The worker in pure science discovers; his fellow in applied science utilizes; the former receives little credit outside of a narrow circle; pecuniary reward is not his object and rarely falls to his lot; the latter has a double possibility as an incentive, large pecuniary reward and popular reputation in case of noteworthy success. The two conditions are well represented by Henry, the investigator, and Morse, the inventor and promoter.

Men are ignorant of their debt to closet workers because the facts have never been presented. As geologists and as citizens of no mean countries we ought to present this matter clearly to men whose fortunes have come through application of principles discovered by obscure workers. Such men are quick to perceive the justice of the claim and usually are ready to pay a reasonable interest on the debt.

The world must advance or retrograde; it cannot stand still. Continued advance in physical comfort and intellectual power can come only through intenser application to investigation along the lines of pure science, which can be made possible only by affording increased opportunities for research in our colleges and the expansion of research funds held by societies such as this.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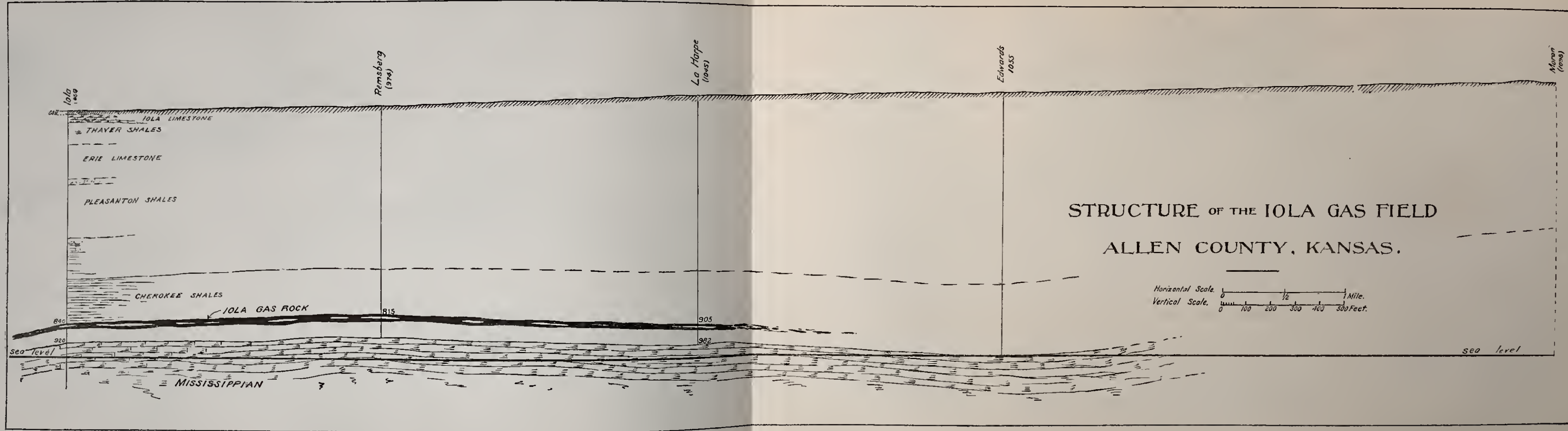

STRUCTURE OF IOLA GAS FIELD OF KANSAS

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GEOLOGICAL STRUCTURE OF THE IOLA GAS FIELD

BY EDWARD ORTON

(Read before the Society December 30, 1898)

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INTRODUCTION

In this country, at least, natural gas is advancing rather rapidly in public appreciation and regard. It is found to be much more widely distributed, both geographically and geologically, and to exist in much larger quantity than any one would have ventured to claim 20 or even 10 years ago. It is no longer an unusual thing for a village or city to enjoy a more or less adequate supply of natural gas as a source of artificial heat and light. There are many such examples in New York, Pennsylvania, Ohio, West Virginia, Kentucky, Indiana, Illinois, and Kansas.

Abundance and geologic Relations of Gas Rock

As to its productive horizons, there is hardly a stratum in the Paleozoic column of the country that is not somewhere, in some of its phases or conditions, a gas rock.

Discussion of Occurrence in General

GAS-BEARING ROCKS

While it occurs in shales, sandstones, conglomerates, limestones, and dolomites, it still remains true that it has its preferences and that its great accumulations are to be found only in certain kinds of strata.

MODES OF OCCURRENCE

The classes.—Two distinct modes of its occurrence are to be recognized: That which prevails in shales and in certain limestones, and that which is found in sandstones, conglomerates, and in a certain class of dolomitic limestones. The rocks of the first group are generally counted impervious, while the porosity of the second group is universally recognized.

The gas found in the first group may be provisionally termed *shale gas;* that of the second group may be provisionally styled *reservoir gas.* These terms are obviously open to criticism and objection, but no other simple terms have been suggested that will avoid the apparent contradictions or erroneous assumptions of those here proposed.

Shale gas.—Gas wells in the two classes of strata named above are sharply distinguished from each other.

1. Shale gas wells are generally of *comparatively small* volume.
2. They *lack uniformity* of *rock pressure.* Wells drilled in close proximity and to the same depth may show very different figures on the pressure gauge.
3. There is *no definite horizon from which their gas supply is derived.* The stratum that yields it may be several hundred feet thick, and gas is likely to be found at any point in the descent. Shale gas wells, though in the same field, may be expected to show a considerable range in depth.
4. Shale gas wells often occur *independently* of *oil production.* Gas may be abundant, while petroleum is altogether wanting. No large oil fields are known in connection with shale gas.
5. Shale gas has *good staying properties.* Weak flows are maintained for long periods. Most of the gas springs that have been flowing from immemorial time are to be referred to this division.
6. Shale gas is *not dependent on the structural arrangement of the rocks* which contain it. Not being associated with oil or water, it cannot be displaced or crowded out by them.

Reservoir gas.—The characteristics of reservoir gas or the gas of porous rocks may be pretty fairly made out by reversing the several statements made for shale gas.

1. The *largest known gas wells*—those, for example, whose volumes run up to tens of million of cubic feet a day—*are all found in sandstones, conglomerates, and porous dolomites.*
2. In a gas field fed by a porous rock the wells *attain the same pressure*, approximately, irrespective of their widely differing volumes. The normal pressure can generally be obtained from one well as safely as from another.
3. In reservoir wells the gas is found at definite horizons. The driller soon learns the depth to which a well must be carried. If he does not find his reward at a certain point in the descent, he knows that he is to go unrewarded altogether.
4. In reservoir wells *oil accompanies the gas* in multitudes of instances. These porous rocks are the great repositories of petroleum the world over. With the petroleum, water is invariably associated. The principle that the philosophers of the sixteenth century asserted so positively, that "nature abhors a vacuum," applies with special force to porous rocks. They are in the large way filled with water, usually with salt water; but the other substances above named, gas and oil, occupy certain limited portions of these porous beds.
5. The *gas of these porous rocks often*, I may say generally, comes to a sudden end. Oil comes in and fills the pipes, or salt water shuts off the gas like a light blown out by a gust of wind. Only by constant care and attention in removing these substances from the pipes can the life of the well be maintained, especially in its later stages.
6. The *structure* or arrangement *of the strata* is found to be *the dominant feature* in the gas production of porous rocks. Not only is a particular kind of rock demanded for the accumulation of gas, but the accumulation is strictly limited to certain portions of the stratum

ANTICLINE AND TERRACE

Two well known structural features are especially connected with the accumulation of oil and gas, namely, the *anticline* and the *terrace*. Both of these have passed, in this connection, beyond the theoretical stage. Their value in the way of petroliferous accumulation is no longer discussed as a possibility, but has been abundantly demonstrated as a matter of fact. A few geologists and oil producers, having the knowledge by which they can read these structures from the surface, are reaping rich rewards by the application of this knowledge.

A few years ago, while controversy as to the possible effect of anticlines was still in progress, some reputable geologists, who happened to be ranged on the wrong side of the question, declared that, instead of gas being confined to anticlines, it was often found in the synclines of porous strata. To them it was replied that we occasionally see on the surface an extensive syncline interrupted by a minor anticline at the bottom of the trough, and that such structure would fully account for the rare cases in which short-lived gas wells are found in synclines. The physical impossibility of gas occurring in the actual syncline of a porous stratum which is jointly occupied by gas and salt water is so obvious that to be recognized it needs only to be named.

The terrace is an incomplete anticline or arch. It is as if nature began to build an arch which she was unable to finish; but like its prototype, the arch, it furnishes a safe harbor or gathering ground for the lighter contents of the warped porous stratum.

It seems to me that the time has now come for the prompt recognition and acknowledgment of the paramount influence of structure in gas fields which are found in porous rocks. We are warranted in affirming an anticline or terrace as an explanation of the gas production of such a stratum, even in advance of the actual discovery of either.

Gas Field under Consideration

EXTENT AND CHARACTER OF FIELD

This line of thought has been suggested to me by an examination that I have recently made of the gas field of Allen county, southeastern Kansas, which is known as the *Iola gas field*. It is small in area, but of great promise in production. Its length in an east-and-west line has been demonstrated by the drill to be at least seven miles, while its breadth, proved in the same way, has been found to exceed three miles.

More than two dozen wells have already been drilled in the field, and the wells range in production from two million to over ten million feet in 24 hours. There are a half dozen of the number, each of which produces about 7,000,000 feet a day.

The rock pressure of the field is 325 pounds, with an outside range of five pounds in a single well.

A little oil has been found, mainly on the western boundary of the field and at a lower depth than the gas. Salt water occurs below both gas and oil, but has not proved thus far aggressive. The height to which it rises has not been determined. It is not less than several hundred feet.

The gas rock is a sandstone of moderate grain, with an average thickness of about 20 or 25 feet. It is occasionally interrupted by wedges of shale, and disappears as a sandstone altogether beyond the boundaries I have named.

All these characteristics stand for a gas field in the second division above named. Every feature of the Iola field indicates a porous or reservoir rock as the source of its gas.

GEOLOGY OF THE REGION

Sources of information.—The geology of southeastern Kansas is comparatively simple. In describing it I rely mainly on the published reports of the geological survey conducted by the state university under the direction of Professor Erasmus Haworth.

The formations—Coal Measures and sub-Carboniferous limestone.—All strata reaching the surface in this section of the state belong to the so-called Coal Measures, with the single exception of the great sub-Carboniferous limestone, which may be regarded as the floor of the eastern half of Kansas. This stratum rises today only in the southeastern angle of the state, and its outcrop does not exceed 45 square miles; but though small in area, it has extreme economic interest and importance, for it carries zinc and lead ores in large quantities. As a source of the former, this 45 square miles is beyond question the most valuable tract known in the United States. Perhaps no equal area in the world exceeds it in this respect. This sub-Carboniferous stratum is coming to be known in Kansas and the adjoining states as the Mississippian limestone. In sinking deep wells it constitutes a particularly valuable landmark, because its flinty beds are certain to attract the driller's notice and are universally regarded by him in his search for petroleum as the "farewell rock." When he strikes this floor he knows that his work is done.

There are large areas of Kansas and adjoining states in which the Coal Measures, so called, do not justify their name. In many long sections furnished by the drill they are found to consist altogether of limestone, shale, and sandstone; but in other districts the series contain important beds of coal, the aggregate of which, as computed, runs into large figures, and constitute an invaluable reliance of all these regions for time to come.

The western Coal Measures have been variously divided by the geologists who have studied them in the several states. It is a pleasure to find that they are coming to a general agreement, which promises at no distant day a harmonious account of this great chapter of our geological history.

Cherokee shales.—In southeastern Kansas, the lowermost division of the Coal Measures, namely, that immediately overlying the Mississippian limestone, is known as the "Cherokee shales." It is counted the equivalent of the "Des Moines shales" of Keyes in Iowa. The Cherokee shales have a thickness of about 450 feet and contain, in certain districts, by far the most valuable seams of coal found in Kansas. Though consisting largely of shale, as the name would lead us to expect, thin courses of limestone and considerable bodies of sandstone also occur in it. Some of the sandstones rise in important and valuable outcrops; but other beds begin and end in the shale series, and for our knowledge of them we are indebted wholly to the driller. They are capricious and unstable to a high degree.

Other divisions.—Above the Cherokee shales come several well marked and easily identified divisions known in Kansas geology as the "Oswego and the Pawnee limestones," about 100 feet in combined thickness, the "Pleasanton shales," about 250 feet thick and carrying in certain localities valuable beds of coal, the "Erie limestone and shale," the "Thayer shale," and the "Iola limestone," together aggregating several hundred feet of strata.

The divisions here named comprise all the strata traversed in the wells of the Iola gas field.

Iola gas rock.—The gas rock already described is one of the unstable, lenticular sandstones of the Cherokee shale, and lies near the bottom of this division. Its upper surface is above 75 feet above the Mississippian limestone.

All these strata are described by Haworth as dipping to the west at an average rate of 17 feet to the mile.

The surface of this portion of the state also slopes to the west, but not as rapidly as the strata descend. The surface slope to the westward is given by Haworth as about 10 feet to the mile. These facts are indicated in the accompanying diagram (plate 11). The elevation of Iola is 956 feet above tide; of Laharpe, 5 miles to the eastward, 1,045 feet, and of Moran, 12 miles east of Iola, 1,098 (see Gannett's Gazetteer of Kansas). This gives an average descent from Moran to Iola of nearly 12 feet to the mile. Other elevations used in this paper were obtained from the aneroid and can not vary far from the true figures.

Iola arch at Edwards well.—At the Edwards well, two miles beyond Laharpe, the Iola gas rock has completely disappeared as a sandstone, but the driller continued his work until he reached the Mississippian limestone, or the "flint," as it is commonly called. This was reached at 1,061 feet, or very nearly at tide level. The same stratum was also struck in one of the wells at Laharpe, but here at a depth of 982 feet, or 63 feet above tide, showing a *rise to the westward* of 31 feet to the mile in place of the normal descent in that direction of 17 feet to the mile.

A low arch, which may, perhaps, with greater propriety be styled a terrace, thus comes into view. So far as present knowledge goes, the arch begins at the location of the Edwards well, in which, as will be remembered, the surface of the Mississippian limestone lies at tide level, The stratum rises to the westward from this point and does not regain tide level until it is followed about 2 miles beyond Iola. At Iola its place is calculated to be 37 feet above tide.

We have thus a stretch of territory about 8 miles in length from east to west in which there is no fall to the Mississippian floor of the section. Its normal dip of 17 feet to the mile would carry it 126 feet below tide in that distance.

The gas rock is not coextensive with the arch, as, it will be remembered, it fails to appear in the Edwards well. If it had continued to that point in its normal volume, its upper surface would have been found 77 feet above tide.

At Laharpe, however, it is found in full force, and its surface here is 140 feet above tide, as determined by the average of two 905-foot wells. It rises 19 feet higher in the next 3 miles, being found at 159 feet above tide in the Remsberg well. This is the highest point of the Iola gas rock, so far as explorations have now gone, and it is interesting to note that this well is the largest producer of gas in the entire field. Its volume exceeds ten million cubic feet a day, which is about three million in excess of any other well in the field. The surface of the gas rock descends 43 feet in the next two miles to the westward. The average depth to the gas rock of two wells at Iola is 840 feet, which shows its surface to be 116 feet above tide. Within the next two miles the Mississippian limestone gets down to tide level again, and this point marks the limit of the Iola arch.

STRUCTURE AS A FACTOR IN INTERPRETATION

It is thus seen that the Iola gas field comes fully into line with a large number of other gas fields that belong to the same class with it. In all of these, *structure* is the dominant factor, a factor which helps us to a rational explanation of the characteristic phenomena of all.

ECONOMIC VALUE

A word as to the use which is to be made of the Iola gas field. It seems certain that it will be devoted in the wholesale way to manufacturing purposes. The zinc smelters of the Joplin district found their way into the gas field almost as soon as its valuable character was established. They bought and leased gas lands wherever they could be secured, and thus, without holding a large acreage, they have gained access to all parts of the field. Five or six large plants are already established here. The experimentation necessary to adapt the fuel to the process has already been successfully accomplished, and the smelters now report the best of results. Others are sure to come in to secure the great advantages of the new fuel. As in the glass industry of the country, after the opening of the Ohio and Indiana gas fields, the center of the manufacture was shifted, so it seems likely to be with the spelter production. The old districts will be unable to compete and will be left to languish as long at least as the gas supply can be maintained. The cities and villages of Allen county will be supplied with light and fuel, and many of the farmers' houses also, within the limits of the field; but the great bulk of this superfine fuel, the best in the world—much better, in fact, than man has learned to make for use in the large way—will be consumed in smelting zinc ores, for which, until this gas was discovered, even inferior grades of Kansas coal were counted good enough.

The highest and really the only proper use of natural gas is household use. In this field it meets the supreme test of doing the greatest good to the greatest number. If the world were wise and if genuine good will controlled the actions of all, every foot of natural gas would be scrupulously husbanded for this service; but the world is not wise and universal benevolence does not yet bear sway.

Against the improper use and wanton waste of natural gas geologists have made earnest but unavailing protest, receiving often the curses instead of the thanks of those in whose interests they have labored. To convince the most intelligent and fair-minded members of a community of the justice and wisdom of the geological view is an easy task; but the thoughtful and fair-minded are never in the majority. Under existing conditions it is simply impossible, at least in this country, to save a promising gas field for the highest uses. Natural gas will be mainly consumed in steam production, iron mills, machine shops, glass factories, zinc smelting works, or even in the coarser service of brick yards and lime kilns. Let us still hope, however, that its use will incidentally educate enough people to the inexpressible advantages of gaseous fuel to pave the way for the introduction of a successor, necessarily a vastly inferior successor, but one which can be held under proper control, and which, therefore, when it comes, will "come to stay," except as it is improved by the growing knowledge of the world.

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IOWAN DRIFT

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(*Presented before the Society December 30, 1898*)

CONTENTS

INTRODUCTION

The sheet of drift in northeastern Iowa, which, in the recent literature relating to Pleistocene geology, is known as the Iowan, has certain individual characteristics that differentiate it sharply from the other drift-sheets of the Mississippi valley. Before McGee's classic work on the region under consideration, no one had suspected that more than one sheet of till was represented in the Pleistocene deposits of Iowa; but the studies of McGee in Iowa and of Chamberlin in Wisconsin led to the very general recognition of the multiple character of our drift deposits. Other investigators, using the methods of observation employed by the pioneer workers named, and guided by the criteria for discriminating different drift-sheets which they pointed out, have been able to map, with a fair degree of accuracy, the limits of the successive ice invasions.

PREVIOUS WORK ON THE IOWAN

The earlier work on the Pleistocene of northeastern Iowa was remarkable in many respects. The energy and intellectual acumen with which the investigations were prosecuted, the enormous mass of details collected and classified, and the masterly way in which the facts were handled, and conclusions of epoch-making significance deduced from them, commanded the admiration of all geologists. Nevertheless, as was practically unavoidable in doing pioneer work in an unexplored field, some important facts were overlooked. Three sheets of till are now known to be present in the area studied, but the hypothesis employed recognized only two; and the attempts to harmonize the drift sections in Bremer, Buchanan, and other counties where the Iowan is typically developed, in accordance with the hypothesis, led to some confusion of statement.

ORIGIN OF THE NAME

McGee applied the names "Upper till" and "Lower till" to the respective drift-sheets which he recognized in northeastern Iowa. It is obvious from numerous statements that what we now call the Iowan drift must be regarded as the typical phase of his upper till. For example, he tells us that the prevailing color of the upper till is yellow or buff, running into gray,* and that boulders,† so large that they rise above the drift as high as houses or haystacks and give character to every landscape, are conspicuous elements of the upper till. Furthermore, the boulders characterizing the upper till are said to culminate in size and abundance in Butler, Bremer, Black Hawk, and Buchanan counties. And so the details of structure and distribution are described so minutely as to leave no possible doubt concerning the particular drift-sheet which stood in his mind as the embodiment of all the typical characteristics of the upper till. There is only one till in all the area described that expresses itself

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* Pleistocene Hist. Northeastern Iowa. 11th Ann. Rept. U. S. Geol. Sur., p. 476.

† Ibid., p. 481. See also the Resume, p. 540.

in a "monotonous simplicity of surface configuration" and in ponderous, boulders projecting conspicuously above the surface. The assumption however, that there were but two till sheets in the area considered, and that they were separated by an old soil and forest bed, was the cause of assigning to the upper till in certain localities a number of characteristics that do not belong to the superficial drift of Bremer, Black Hawk, and Buchanan counties. Taking the latest glacial deposit of these counties as the true upper till of McGee, we have a drift-sheet characterized by definite and consistent individuality and sharply delimited in its geographic distribution.

In the third edition of Geikie's "Great Ice Age" Chamberlin proposes the name East Iowan for the upper till of McGee.* The characteristics of the formation are enumerated in detail, and are made broad enough and variable enough to include all the Pleistocene deposits down to the forest bed, which is so conspicuous a feature of the drift series not only in Iowa but very generally throughout the Mississippi valley. Somewhat later,† following the suggestion of Mr Upham, Chamberlin abbreviated the term to Iowan, and it is needless to say that the shorter name was welcomed and has since been very generally adopted. Chamberlin's latest classification of the glacial series of the Mississippi basin recognizes the limitations assigned in this paper to the Iowan drift.

Area occupied by the Iowan Drift-sheet

The Iowan drift as at present recognized is superficial over an area in northeastern Iowa and southeastern Minnesota east and southeast of the Altamont moraine. In Iowa the moraine bounding the Iowan area on the west passes southward from near the middle of the north line of Worth county. It includes Clear lake in one of its basin-like depressions, and gradually fades out in Hardin and Marshall counties. This moraine marks the eastern edge of the Wisconsin lobe and overlaps the Iowan from the Minnesota state line to near the southern boundary of Hardin county. South of Hardin county the Wisconsin drift rests on a till that is very much older than the Iowan, on what has recently come to be called the Kansan.

The southern limit of the Iowan till coincides in a general way with the course of the Iowa river from near Albion, in Marshall county, to the great elbow west of Solon, in Johnson county, from which point the general trend is eastward to near the mouth of the Wapsipinicon river.

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*James Geikie: The Great Ice Age, third ed., p. 759.

†The Journal of Geology, vol. iii, pp. 270 and 273; vol. iv, p. 874.

The eastern or northeastern boundary cuts the Iowa-Minnesota line near the northwest corner of Winneshiek county. Its course from this point is, in the main, southeast, cutting across the northeast corner of Fayette and the southwest corner of Clayton. It clips off the northeastern corner of Delaware county, is exceedingly sinuous in the western part of the county of Dubuque, trends southward with many tortuous windings through Jones, and finally sweeps eastward, six or eight miles south of the north line of Clinton county, to the Mississippi river. The free edge of the Iowan ice, however, flowed out in numberless digit-like lobes, some of which were surprisingly long and narrow, and so its boundary lines along the terminal margins are irregular and sinuous to the last degree. Except at one or two points, the eastern boundary of the Iowan falls short of the western edge of the Driftless area, the space between the extreme limits of the Iowan in this direction and the Driftless area being occupied with typical weathered Kansan overlain by loess.

CHARACTERISTICS OF THE IOWAN DRIFT

TOPOGRAPHY

The Iowan drift presents a number of very constant, easily recognized, specific characteristics. In the first place, the topography is very striking. The surface is a broad plain, marked by long, gentle, sweeping undulations. The curves are low and flat, and the concave portions of the profiles are in many cases longer than the convex. Erosion since the retreat of the Iowan ice has played no part in producing the main topographic forms. The surface inequalities are irregularly disposed and are due, for the most part, to the erratic heaping up of materials, in some places more than in others, by the action of the Iowan ice. The main drainage courses are fairly well defined, many of them following sags determined by the presence of partly filled pre-Iowan valleys of erosion. Along the larger streams incipient erosion forms occur, extending back as small lateral channels and intervening ridges for a fraction of a mile or so; but the development of such forms is always on a small scale, and over the intervening spaces, which constitute by far the greater part of the Iowan area, the drainage is effected by flow of water along the broad, shallow depressions of the surface, without following definitely cut channels. Even in the case of the principal drainage courses the amount of stream-cutting since the retreat of the Iowan ice is insignificant. The channels in the typical portion of the area are mere troughs or canals cut but little below the level of the broadly undulating drift-plain. The streams have no valleys, nor have they any floodplains, and hence farms having the general level of all the surrounding country are cultivated in places to the water's edge.

CLAY CONSTITUENT OF THE TILL

Color and composition.—The Iowan till, as a rule, is a pale yellow clay, rich in minutely divided lime carbonate and carrying many pebbles, cobbles, and small boulders that, with scarcely an exception, are all of foreign origin. Limestone fragments are comparatively rare. The upper part of the till has been modified by a number of agents, the most pronounced change being due to the development of a deep, black, surface loam varying from a few inches to two or three feet in thickness.

Condition as to weathering and leaching.—The absence of signs of weathering in the upper zone of the Iowan till is a very prominent characteristic, especially to one familiar with the strongly pronounced ferretto zone resulting from weathering in the older sheets of drift. The Iowan is practically unweathered. Oxidation is no more perfect at the surface than at the bottom, and the reaction for lime carbonate is as energetic at the grass roots as it is ten feet beneath the surface. Absence of oxidation and leaching is one of the distinguishing characteristics of the Iowan when compared with the older drift-sheets of the Mississippi basin.

IOWAN BOULDERS

Composition, size, and weathering.—Among the more conspicuous features of the Iowan drift are huge boulders of crystalline rocks scattered in great numbers over the surface of the region in which the formation is typically developed. In no other drift-sheet are boulders so prominent a characteristic of the prairie landscapes. In composition the majority of the boulders are light colored, coarse textured granites, in which large crystals of feldspar are the most abundant constituent. A few quartzite boulders occur, and there are some of the dark fine grained traps, basalts, and greenstones, but these are inconspicuous in size as well as in numbers. The prevailing types are granites, and the great size of some of the individual masses is such as to excite the interest and attention of even the most casual observer. Granite boulders 30 feet in diameter are not uncommon. In certain localities, for the distribution is not uniform, blocks having diameters ranging from 12 to 20 feet may be counted by the score on every square mile, while boulders varying from 2 to 6 feet across can be reckoned by the hundreds within the limits of an ordinary farm. Furthermore, the granites, as a rule, show little or no signs of decay from weathering during the period of their exposure since the retreat of the Iowan ice. The majority are perfectly sound even at the surface; and the more massive ones have been utilized as granite quarries from which contractors have taken large amounts of valuable building material, as fresh as if it had been taken directly from the native ledges.

Superficial position.—At the risk of repetition, I would again emphasize the great size of some of the Iowan boulders and the prominence of many of them above the surface of the ground. The common comparison with houses and haystacks, suggested to every observer, is by no means strained; for some of the ponderous blocks rise 12, 15, or 20 feet above the prairie sod. While a large number of the boulders are completely embedded in the till, and while others are buried to a greater or less extent, there are yet many that seem to rest practically on the surface with their whole mass exposed above ground. At all events, they are no more embedded than would naturally be the case if they had been carefully laid on the surface a century or two ago. All their surroundings preclude the theory that they owe their present prominence to erosion and removal of the finer constituents of the drift; and the further fact that nearly all those which have been quarried were found planed and worn to a true, flat face on the lower side equally precludes the theory—even if there were not other insuperable objections to it—that they were superglacial during the period of their transportation. These superficial granites were probably completely embedded and incorporated in the ice, with their lower surfaces in position to be abraded and worn, yet coinciding with the bottom of the glacier, while the detrital matter constituting the ground moraine occupied the true subglacial position. There are reasons for believing that the amount of clay and other fine material carried beneath the Iowan ice was, locally at least, very small, for Iowan boulders not infrequently rest directly on residual clays, on Kansan drift, or on bald rocky surfaces, the proper Iowan till being absent.

THICKNESS OF THE IOWAN DRIFT

The Iowan sheet of till is comparatively thin. While boulders were large and numerous, the finer materials transported by the Iowan ice were decidedly scant. In many cases they were insufficient completely to obscure the pre-Iowan topography. For example, the present drainage is very largely controlled by imperfectly disguised valleys which had been previously eroded in the surface of the Kansan till; and in not a few instances the hills which have to be cut in making railway grades are pre-Iowan ridges with Kansan drift rising within a few inches of the surface. In the great cut at Oelwein, Fayette county, the Iowan till is represented by a layer of loamy soil less than a foot in thickness, while a short distance to the southeast, in Fairbank township, Buchanan county, the farm wells show 30 feet of the yellow, calcareous till peculiar to this age resting on highly oxidized beds of Buchanan gravel.* What the maximum thickness over the pre-Iowan valleys may be has not been determined, but the thickness in general is less than 20 feet, and over large areas the average may be less than 10 feet.

Relation of the Iowan to the "Forest Bed" of Northeastern Iowa

Remains of a forest bed which was overwhelmed and buried by advancing glaciers are conspicuous in many of the drift sections in northeastern Iowa. The abraded and splintered wood is distributed through a zone a number of feet thick, but it is most abundant in connection with, or just a little above, a definitely marked soil band and peat horizon. The principal belt through which forest material is distributed lies above the soil and peat. The soil band, peat beds, and forest remains are all evidence of an interglacial age of longer or shorter duration, for there is a heavy underlying till sheet that is older than either soil or forest. Accordingly, in dividing the Pleistocene deposits of the region under consideration into a lower and an upper till, it was most natural that the soil, peat, and forest horizon should be adopted as the line of separation. For some time after the sheet of till we now call Kansan had been differentiated from the true Iowan by evidences of erosion and weathering, the belief in a forest bed below the Iowan and above the Kansan was still entertained. The differentiation of the Iowan and Kansan till sheets was made as the result of studies carried on along or near the margin of the Iowan drift. The two deposits were strikingly different. That they were separated by an immensely long interglacial interval was as clear as noonday. It was the unquestioned belief when the names Kansan and Iowan were applied to the two drifts we are now considering that one was the upper till and the other the lower till of McGee, and that they were the formations to which the names Iowan and Kansan had been applied by Chamberlin. If there was a forest and soil bed, it must be between these two deposits, for as yet there was no evidence that there were more than two deposits to be taken into consideration. Gradually, however, as available sections were multiplied and opportunities for study were enlarged, it was found that the forest bed and soil band were invariably located beneath the drift we had been calling Kansan, and that no section anywhere revealed the presence of forest material immediately beneath the typical Iowan. A ferretto zone is there, with most convincing evidence of prolonged and profound weathering, but no soil band, no buried forest—at least, none in any way comparable with the wealth

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* Iowa Geol. Survey, vol. iii, p. 245. Des Moines, Iowa, 1898.

of vegetable matter buried in and beneath the drift we have all learned to call Kansan. The forest zone separates the Kansan of the later literature relating to the Pleistocene from the oldest drift of the region, so far as known, from the lately added member of our Glacial series—the pre-Kansan or sub-Aftonian till.

COMPARISONS WITH OTHER FORMATIONS

IOWAN COMPARED WITH THE KANSAN

The Iowan drift in northeastern Iowa rests directly on what has come to be called the Kansan, or on the secondary product of the Kansan, which has been described under the name of the Buchanan gravels. The Kansan becomes the superficial till around the southern and eastern borders of the Iowan. Whether this till bordering and underlying the Iowan is in reality the deposit to which the name Kansan was originally applied, need not now be argued. It is sufficient to say that it is the formation which all recent writers on Pleistocene geology have, by common consent, adopted as the Kansan, and it is to be hoped that the present usage will not be changed.

The contact relations of the Iowan and Kansan constantly invite comparisons between the two drift-sheets, and such comparisons bring out a number of striking differences. In the area under consideration the Kansan contains none of the large coarse textured boulders that are so characteristic a feature of the Iowan. Kansas boulders are relatively small. Very rarely do they exceed 4 feet in diameter, and in a majority of cases the diameter is less than 10 inches. Dark, fine grained green-stones are common in the Kansan and rare in the Iowan, and the same is true of limestone fragments and pebbles. The till of the Kansan is normally blue, while the Iowan is yellow. In the intervals or intervals* between the Kansan and the Iowan the upper part of the Kansan was profoundly modified by aqueous and atmospheric agencies. The changes wrought in these intervals are expressed in (1) erosion, (2) oxidation, (3) leaching, and (4) in the decay of the contained boulders in the zone of weathering. 1. The Kansan surface was very deeply eroded, and mature erosional topography was completely developed before the Iowan drift was laid down on it. 2. The surface was weathered and oxidized to a depth of from 6 to 12 feet, as shown in many recent exposures. The oxidation is most complete in the upper 3 or 4 feet, from which depth there is a gradual transition to the normal blue, unweathered phase. The weath-

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*Leverette has shown that three stages of the Glacial series are represented by the interval between the Kansan and the Iowan. These are respectively Yarmouth (interglacial), Illinoian (glacial), and Sangamon (interglacial).

ering, however, descends along joints in the blue clay to a depth of 20 or 30 feet. 3. The lime constituent of the Kansan till was completely removed from the weathered zone, partly by leaching and probably in part by the growth of vegetation during the long interglacial intervals. That leaching was the process most effectual in the removal of the lime carbonate is indicated by a zone, from 8 to 12 feet below the surface, charged with calcareous concretions resembling loess-kindchen. These concretions evidently represent, in concentrated condition, the lime carbonate originally distributed through the overlying portion of the till. The material composing them was doubtless carried in solution by descending waters which were probably charged with carbon dioxide from decaying vegetation. Below the zone of leaching the blue Kansan till is decidedly calcareous. 4. Finally in the weathered zone certain kinds of granites, as well as boulders of some other rock species, are completely softened and decayed.

That the erosion, oxidation, leaching, and rock decay enumerated above took place before the advent of the Iowan ice is clearly indicated by numerous facts. In the first place, there is convincing evidence respecting all the characters named beneath the Iowan drift, but the deposition of the Iowan covered up and protected the Kansan surface and put an end to all the processes that worked for change. There has been no change since. The Kansan surface is in the precise condition it was when the Iowan was laid down on it. In the second place, an examination of the belt, 4 or 5 miles wide, just outside the Iowan margin, discloses a very large number of satisfactory sections supporting the same conclusion. When the Iowan ice was at its maximum a heavy body of loess was laid down within this belt, and indeed for many miles beyond it. The loess was thick enough to protect the Kansan surface from the effects of the atmosphere, as did the Iowan till in the intra-marginal area. Since the settlement and cultivation of the country rainwash has cut deep trenches in the fields and along the roadsides, and so has revealed in hundreds of instances the significant fact that the loess was moulded over an eroded, oxidized, and leached surface of Kansan till, the upper zone of which was characterized by the presence of numerous boulders so far decayed that they fall to pieces by their own weight. On the other hand, the Iowan surface is not eroded to any measurable extent, the surface presents no signs of oxidation or leaching, and the granitic boulders show practically no indications of decay. Measured by the effects produced the interval between the Kansan retreat and the Iowan invasion was many times the length of all post-Iowan time. Taking account of all the facts, it would not seem extravagant to say that it was 50 times as long. It would certainly be very conservative to estimate it at 15 or 20 times the length of the post-Iowan interval. The Iowan surface, with very rare and insignificant exceptions, is free from loess, whereas the Kansan surface is almost universally loess-covered, except where it is overlain by other sheets of drift.

IOWAN COMPARED WITH THE ILLINOIAN

The differences between the Iowan and the Illinoian are relatively not so very great. The Illinoian surface, it is true, shows distinct effects of erosion, oxidation, and leaching, but these processes have been carried to a far less extent than in the case of the Kansan. The color of the Illinoian till, where fresh and unweathered, is quite like that of the Iowan, and the boulders are somewhat similar, though very much inferior in average size. The Illinoian surface, like that of the Kansan, is very generally covered with loess. Judging by the changes that had been wrought in the surface of the Illinoian before the loess was laid down on it, this sheet of till is at least 5 or 6 times as old as the Iowan.

IOWAN COMPARED WITH THE WISCONSIN

The Wisconsin drift is represented in Iowa by the Des Moines lobe. From Hardin county northward the eastern edge of this lobe overlaps the Iowan, and the relations are such as to offer ready facilities for making comparisons between the two sheets of till. Compared with the Iowan the clay of the Wisconsin is paler or lighter yellow; it is very much richer in calcium carbonate and, in striking contrast with the Iowan, it is crowded with countless numbers of limestone pebbles. The crystalline boulders, as a rule, are smaller, and they are never so numerous as they are in some parts of the Iowan area. The surface has suffered no appreciable change since the withdrawal of the Wisconsin ice. There has been practically no erosion. One may travel scores of miles without seeing a definite stream channel of any kind. Numerous undrained kettle holes and depressions characterize the broadly undulating expanses of prairie. There are no detectable signs of even the incipient stages of oxidation and leaching. Everything indicates that in point of age the Wisconsin is even younger than the Iowan, but is more nearly related to the Iowan in this respect than is either of the other drift-sheets of the Mississippi valley. It may safely be said that the Iowan is not more, or certainly not much more, than twice as old as the Wisconsin. Both of these drift-sheets are young when compared with the Illinoian; very young when compared with the much older Kansan.

West of the Wisconsin area in northwestern Iowa there is a sheet of till older than the Wisconsin and younger than the Kansan, which has been regarded provisionally as the equivalent of the Iowan east of the

Wisconsin lobe. More recent studies in this region have cast some doubt on the Iowan age of the till in question. The erosion, oxidation, and leaching of the surface is very much greater than in the typical Iowan of northeastern Iowa, and furthermore a mantle of loess is moulded over the irregularities of the surface. The Iowan drift in the typical area is all but universally free from loess.

THE IOWAN MARGIN

ITS SINUOSITIES AND DIGITATIONS

There are reasons for believing that the Iowan ice was very thin at the margin, and the same attenuation must have characterized it for a number of miles back from the margin. This thin condition of the marginal portions of the ice-field is inferred from the fact that the ice seems to have been incapable of overcoming hills or prominences of any considerable altitude. Furthermore, the ice for some reason was unusually motile and seems to have been capable of flowing completely around obstacles that it did not surmount, even when the obstacle was a highland area embracing a score or more of square miles. The same motility is indicated by the fact that, along its free margins, it had the habit of flowing in numerous long, digit-like lobes wherever the ground was low and favorable, the marginal lobes being usually separated from each other by reentrant angles occupied by slightly higher ground that the ice did not overflow. Accordingly the margin of the Iowan area is very sinuous, and many unexpected eccentricities of distribution are encountered in tracing it in the field.

LOESS RIDGES ALONG THE MARGIN

The North Liberty and Solon lobes of Johnson county, separated by the loess-covered Kansan highland traversed by the Iowa river, afford a good illustration of this peculiar characteristic. The Cedar river, from a point above Cedar Rapids, has carved its valley in another highland of the same kind, and it is this loess-covered Kansan ridge that separates the Solon lobe from a narrow and very typical tongue of Iowan that runs down to the little town of Buchanan, in Cedar county. Tipton is situated near the western edge of a low, broad, interlobular, loess-covered region of Kansan drift. The Wapsipinicon valley was followed in its lower course by a long, narrow lobe of Iowan ice which pushed down to Clinton and across the Mississippi river. On the east side of the river this ice-lobe encountered an insurmountable barrier in the low bluffs which mark the boundary of the floodplain.

The most erratic lobes observed occur in Dubuque county. One having an average width of less than 3 miles begins at Dyersville and extends to a point 5 miles southeast of Farley. The total length of this lobe is about 13 miles, and it shows a number of distinct lobulations, particularly at its southeastern extremity. A moderately high ridge of Kansan overlain with loess, less than 3 miles wide, separates the lobe described from another and more slender Iowan area which begins near Worthington and continues southeast for a distance of nearly 20 miles. This last area is constricted at one or two points to very narrow dimensions. Rocky cliffs encroach upon the low plain that afforded the opportunity for the extension of the thin ice-lobe, and in passing them the ice-stream was reduced in width to a few hundred yards, after which it broadened out again where the surface configuration rendered such broadening possible. Both of the lobes noted blend into the general Iowan plain west of the Dubuque county line.

A short distance north of Dyersville the Iowan boundary crosses into Delaware county and follows a very sinuous line to the middle of the north line of the county named, whence it passes with similar windings through the southwest part of Clayton into Fayette, and maintains the same sinuous characteristics through Winneshiek county to the state line.

RELATION TO MARGIN OF KANSAN ALONG EDGE OF DRIFTLESS AREA

Along its eastern and northeastern border the Iowan ice failed to reach the limit attained by the Kansan, and so a belt of loess-covered Kansan, varying from 1 to 15 miles in width, occurs between the edge of the Iowan plain and the Driftless area. The main body of the Iowan ice, for example, halted near the west line of Dubuque county; only a narrow lobe pushed out in the Dyersville-Farley area, and it stopped just west of Epworth; but east of Peosta there is a railway cut 35 feet in depth in a ridge of typical Kansan drift.

RELATION TO DISTRIBUTION OF LOESS

The geographical distribution and physical characteristics of the typical loess of northeastern Iowa suggest genetic relationship with the Iowan till. That it was in some way derived from the till when the Iowan ice invasion was at its maximum is indicated by many lines of evidence. The main body of the loess is all extra-marginal. Over no considerable area is typical loess ever found resting on Iowan drift. It is thickest just at the margin of the region occupied by Iowan ice at the time of its maximum development, and is spread widely, but not uniformly, over the extra-marginal space to distances at present undetermined. Loess, or a product resembling loess, was developed in connection with more than one drift-sheet, and it is possible that the Iowan loess blends into loess-like deposits of different age in some portions of the extra-marginal territory.

PAHA AND LOESS-KANSAN ISLANDS NEAR IOWAN MARGIN

There are ridges and hills and other areas of considerable extent covered with loess inside the true Iowan margin. Among the loess-covered topographic forms occurring in this situation are the beautifully rounded prominences called "paha" by McGee. The paha are characteristic of the marginal zone of the Iowan, being limited to a space 5 or 10, rarely 20, miles wide, inside the extreme margin of the Iowan drift. The paha are covered with loess. They rise sometimes abruptly from the Iowan drift-plain. An examination of their structure shows that the loess was moulded over a core of rock or Kansan drift which stood prominently above the general surface before the oncoming of the Iowan ice. The thin ice was divided by the prominence, flowed around it, and left it as an island in the frozen sea, to receive, like true extra-marginal territory, its mantle of loess. There is as yet no positive evidence that any Iowan drift was ever deposited over the summit of the prominent core of any paha before the loess was laid down upon it.

Besides the paha, there were in the marginal belt of the Iowan area a few anomalous highlands, embracing in one case at least as much as fifty square miles, that were surrounded but not overflowed by Iowan ice. Like other surfaces that were at the time free from ice, these were deeply covered with loess. In these larger islands there are none of the characteristics of the true Iowan area. The loess rests on weathered Kansan drift or on residual cherts and clays. There is no Iowan till, nor is there a sign of an Iowan boulder. The topography conforms in all respects to the type that distinguishes the extra-marginal area. The general aspect of the island-like plateaus rising above the Iowan plain and surrounded by Iowan drift, as well as the structure and other characteristics of the surface deposits, proclaim these as regions which had never been invaded by Iowan ice.*

The unusual behavior of the Iowan glacier, which expressed itself in long, narrow, marginal lobes and isolated island-like spaces which the ice surrounded but did not overflow, may possibly be accounted for by conditions which seem, in some cases at least, to have attended the deposition of the Iowan loess. So far as this loess is of aqueous origin, the phenomena lend support to the view that during the maximum advance

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* For a fuller account of some of these anomalous areas surrounded by Iowan drift, yet retaining all the characteristics of the extra-marginal territory, see the Report on Delaware county, Iowa Geological Survey, vol. viii, p. 132. There is one similar area in Buchanan county. See same volume, p. 210.

of the Iowan ice the altitude of the Mississippi valley was low, and that the country extending outward from the Iowan margin was flooded with practically stagnant water. Admitting such a possibility, it follows that the weight of the ice at its edge was partly supported by water, that the friction between the ice and the ground was consequently reduced, and that by reason of the diminished friction the motility of the ice was greatly increased. This is offered, with many misgivings, merely as a suggestion to account for the remarkable power of flowing out in long tongues and meeting around prominent elevations that seems to have characterized an unusually thin sheet of ice.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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GLACIAL SCULPTURE IN WESTERN NEW YORK*

BY GROVE KARL GILBERT

(Presented before the Society December 30, 1898)

CONTENTS

INTRODUCTION

The question whether the Pleistocene ice-sheets accomplished a large amount of rock erosion has been a fruitful subject of discussion. The most diverse views have been expressed, and there are probably still some geologists who think that the ice executed only a slight superficial scraping and polishing, as well as others who ascribe to it works of such magnitude as the excavation of the basins of the Laurentian lakes. The most important recent contribution is by Goodchild, who shows that the topography of a large district in Scotland, a district largely occupied by sandstones, breccias, and other resistant rocks, was remodeled by Pleistocene ice. Its topography is rugged in detail, comprising many hills and valleys, and these features, instead of conforming in trend to the strike of the rocks, conform to the direction of ice motion, which makes wide angles with the strike.†

In line with his conclusions are the phenomena of the Finger Lakes region in western New York. Many of the more striking features of that region have been ascribed by various writers to ice sculpture,‡ and my own observation, which has been somewhat extensive, supports that conclusion. It appears to me that the peculiar topographic facies of the great body of Devonian shales underlying that district owes more to ice work than to antecedent water work, and that the face of the country is

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* The observations set forth in this and the two following papers were made by the author as a member of the U. S. Geological Survey, and are here published with permission of the Director of the Survey.

† J. G. Goodchild: Glacialist Magazine, vol. iv, 1896, pp. 1-7.

‡ See Bull. Geol. Soc. Am., vol. 5, pp. 339-356.

essentially a moutonnée surface, the bosses of which are measured horizontally by miles and vertically by hundreds of feet.

While the glacial sculpture of this district is probably as profound as in the district described by Goodchild, the indicated work is less, because the softer rock offered less resistance, and in northern New York, where the rocks are comparable in hardness with those of the Scottish district, the ice seems to have accomplished comparatively little. Sandstones and limestones are not there so disposed as to afford good comparative data; but in a tract of crystalline schists lying northeast of Carthage, and nearly bare of drift, the sculpture features are very different from those depicted by Goodchild. The principal structure of the schist is vertical, and its trend makes wide angles with the direction of ice motion. The ridges, which are at most only a few scores of feet in height, conform in trend with the strike of the foliation, and have been but slightly remodeled by sculpture on lines of ice motion. The bosses of the moutonnée pattern are measured by yards or rods.

While these observations tell of ice action much less energetic than in Goodchild's Scottish field, they do not conflict with his conclusions, but merely show that local conditions were different. Whatever the general potency of glacial ice, a wide variation of local power should be assumed, and the extent to which ice is responsible for the topography of a district is ordinarily a problem to be solved only through the study of local phenomena. The question of the origin of the basins of the Laurentian lakes and of the share of work borne by ice is, in my judgment, by no means insoluble, but will yield eventually to the careful accumulation and scrutiny of available facts. The present paper, while avoiding the general discussion, presents a body of facts which it is hoped may contribute to the observational basis of the ultimate discussion.

During the summer of 1898 my field work as a member of the United States Geological Survey consisted in the detailed mapping of a district along the shore of lake Ontario in New York extending from the Niagara river eastward about 30 miles to the eastern boundary of Niagara county. Reconnaissances had previously covered Orleans and Monroe counties, so that some of the conclusions reached in the district of detailed work could be extended with fair approximation from the Niagara river to the Genesee.

Observations on glacial sculpture pertained to the Niagara limestone, the ledges at the base of the Niagara escarpment, and the Medina shale.

Sculpture of the Niagara Limestone

In western New York the strata incline gently toward the south, the rate varying usually between 25 and 50 feet to the mile, but the general surface slope is toward the north. It results that the various formations reach the surface in parallel belts running east and west. Some of the harder rocks find topographic expression in lines of cliff facing northward, and this is especially true of the Corniferous limestone and Niagara limestone, each of which is a resistant sheet interleaved between thick formations of more yielding material. The Niagara cliff is the more northerly and runs parallel to the lake at a distance of about 10 miles.

The Niagara limestone is here 190 feet thick. Only a small portion is exposed in vertical section along the cliff; the remainder is beveled off so as to present an inclined plain 8 or 10 miles broad. This plain descends southward, the southern boundary of the outcrop being 50 to 75 feet lower than the northern. The configuration of the rock surface is in general concealed by drift, but a few prominences are exposed. The outlines of these trend in various directions and do not conform to the direction of ice motion.

FIGURE 1.—*Profile and Section in western New York from the Corniferous Terrace to Lake Ontario.*

Vertical scale five times the horizontal. Distance represented, 25 miles. Baseline at sealevel. *C*, Corniferous limestone. *N*, Niagara limestone. *L*, shore of lake Ontario.

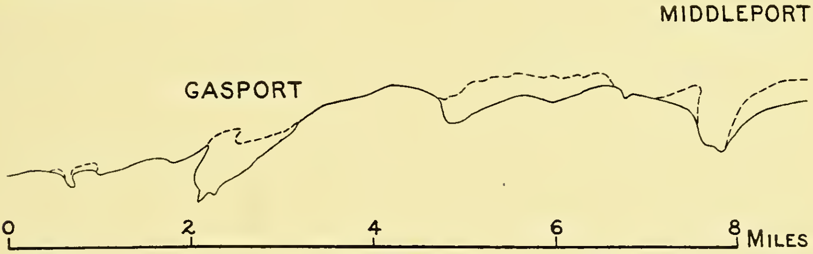

FIGURE 2.—*Map of Niagara Limestone and Escarpment.*

The locality is near Gasport and Middleport, New York. The full line shows the boundary between the Niagara limestone (south) and the Niagara shale (north). The broken line shows the position of the Niagara escarpment where not coincident with the boundary of the limestone.

The northern boundary of the formation and the associated cliff were examined in detail through a space of 30 miles. For the greater part of this distance the rock is exposed to view in the crest of the cliff, but elsewhere it is more or less buried, and observation was less satisfactory. A notable, and to me surprising, feature is the absence of the limestone from the cliff through considerable spaces. From Middleport westward for a distance of 7 miles only about one-half of the cliff is capped by limestone, the remainder exhibiting the underlying shale. The accompanying map, figure 2, shows the relation of the limestone to the cliff in this region. When not coincident with the cliff, the boundary of the limestone could not be mapped in detail, as it is largely covered by the drift, but its approximate position was inferred from the records of wells and the distribution of limestone boulders in the drift.

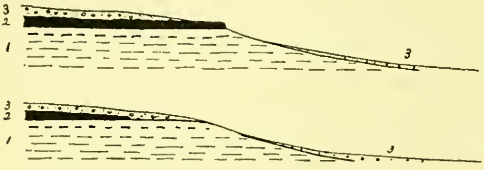

FIGURE 3.—*Typical Profiles of the Niagara Escarpment.*

The profiles are drawn with and without the Niagara limestone. 1, Niagara shale. 2, Niagara limestone. 3, Drift.

The first question for which answer was sought at the beginning of the work was the radical one, whether the Niagara escarpment belonged to the preglacial topography or had been created by ice erosion, and this question seems to be answered by the phenomena already described. The occasional absence of the limestone from the crest of the escarpment suggests that the action of the ice may have tended even to obliterate the cliff; and certainly if it had created the cliff by rapid erosion of the shale where unprotected by the limestone, we could not expect it to reverse the process and uncover the shale by carrying away the protecting armor. Moreover, the southward slope of the plain on the back of the limestone—a slope in the direction of the dip, but opposed to the general descent of the region—is characteristic of subaerial and not glacial erosion, and the failure of minor ridges of that surface to conform in trend to the direction of ice motion indicates that the surface received comparatively little modification from the ice. All the more general features of the limestone belt thus seem to be preglacial.

From the Niagara river eastward to Lockport, a distance of nearly 20 miles, the edge of the limestone is almost continuously exposed to view, and with slight exception it coincides with the escarpment. The general course is east and west, but the outline is diversified by salients and reentrants, so that the cliff may be divided into two sets of courses, the one trending south of west and the other south of east. The general direction of ice motion in the region was toward the southwest, and it was thus diversely related to the two cliff trends. Where the cliff face trends toward the southwest, or approximately in the direction of ice motion, its contours are simple. Where it trends toward the southeast, so as to make a wide angle with the direction of ice motion, its contours are deeply inflected or serrated, the axes of serrations being parallel to the glacial striæ. In other words, the portions of cliff whose faces were directly opposed to the ice advance are characterized by furrows, and the portions met by the ice at a small angle are free from furrows. The furrows have smooth sides and bottoms, the latter rising slowly to the level of the plain, and their configuration is in all respects characteristic of glacial erosion. They range in depth from 10 to 30 feet, are usually several hundred feet broad, and the longest probably extends more than a half mile into the plain. The diagram in figure 4 shows the general character of the rock contours, but without representing any individual contour at equal height above the sea. The equivalent topographic outline is less sinuous, because the rock furrows are largely filled by drift.

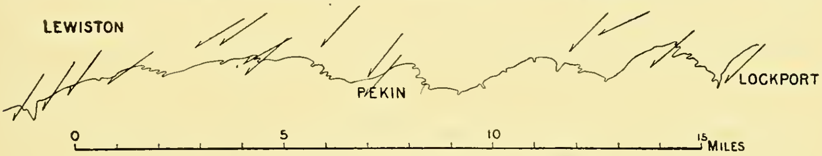

FIGURE 4.—*Contour on the Niagara Limestone at the Niagara Escarpment.*

The escarpment faces north. Arrows show observed directions of glacial striæ.

The configuration of the cliff seems to show that in the regions where the trend is southwest all minor salients have been pared away by the ice, and that where the trend is southeast minor irregularities of the face have been exaggerated and small reentrants drawn into furrows; but the principal salients and reentrants of the topography are preserved, and ice modification is limited to minor details of form.

Considering this evidence of cliff sculpture, in connection with the removal of the limestone in the Middleport region and the non-glacial shapes of the rock ridges of the upper plain, it would appear that the ice-sheet concentrated its work, so far as the Niagara limestone is concerned, on the crest of the escarpment, and that even there its results were of secondary rather than primary importance. Probably the limestone at its escarpment lost on the average only 10 to 20 feet of thickness, and from the broad belt of outcrop the general loss may have been as small as 5 feet.

SCULPTURE OF THE CLINTON AND MEDINA LEDGES

Beneath the Niagara limestone are 80 feet of shale belonging to the Niagara formation; then 25 feet of limestone (Clinton), and then a great body of shales (Medina and Hudson River), containing a few sandstone lenses near the top. The Clinton limestone and the sandstone ledges are strong beds, but the remainder of the section consists of weak shale, opposing little resistance to erosion. The Clinton limestone is continuous and uniform, the sandstones discontinuous. The sandstones lie at various depths below the limestone, ranging from 40 to 100 feet. The heaviest sandstone is 20 feet thick at Lewiston, diminishes eastward in a few miles to 4 feet, then thickens to 14 feet, and finally disappears near

Pekin. After an interval of 4 miles another lens appears at about the same horizon and continues eastward for 20 or more miles, being accompanied near Lockport by two other lenses, one above and the other below.

In preglacial time the topography of the country was presumptively of subaerial type. As the Niagara escarpment was then in existence, the land was not at baselevel, and the general features of a larger district show that the slope of the country was then, as now, toward the north. We may assume, therefore, that the land north of the escarpment was traversed by north-flowing streams and was characterized by a system of parallel valleys and interstream ridges. In passing each stream valley the outcrops of the ledges were deflected southward, and in passing the intervening ridges northward, so that the outline of each outcrop comprised a series of reentrants and salients. This scalloped pattern is not now found, and its absence is to be ascribed to ice sculpture. Each ledge has lost its projecting capes, and may have lost a large territory in addition. At two points near Pekin, where the Clinton limestone has no support from underlying sandstone, it has been eaten back to the very base of the Niagara cliff, and the same is true for a space of several miles near Lewiston, although there its resistance was reenforced by that of a strong sandstone ledge. On the Canadian side of the Niagara river not only are the limestone and sandstone worn back to the Niagara escarpment, but the underlying shale has been removed to a depth of about 40 feet, so that the whole escarpment has a height of 250 feet, with the outcrop of the Clinton limestone midway on the slope. No data have been found on which to base an estimate of the extent to which these ledges have been eroded, but it seems clear that the belt of removal was much broader than in the case of the Niagara limestone, so that the Niagara escarpment was rendered more prominent than formerly by the erosion of material at its base.

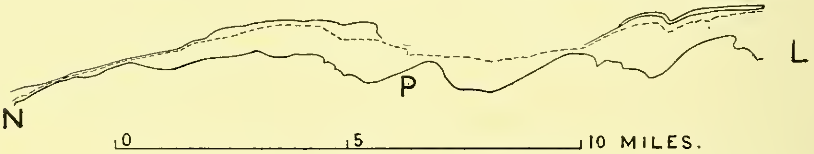

FIGURE 5.—*Plan of the northern Boundaries of resistant Ledges.*

The lower (south) full line is the boundary of the Niagara limestone. The broken line is the boundary of the Clinton-limestone. The upper full lines are boundaries of sandstone lenses of the Medina formation. *N*, portion of Niagara river. *P*, Pekin. *L*, Lockport.

SCULPTURE OF THE MEDINA SHALE

The main body of the Medina formation below the sandstone ledges consists of red shale and has a thickness of several hundred feet. This underlies a plain about 7 miles broad, sloping northward from the foot of the escarpment to the shore of lake Ontario and descending in that distance 100 to 175 feet. If this plain were featureless, each traversing stream would follow the shortest path to the lake and its course would be normal to the lake shore. In fact, however, only a few streams take this direct route, and the majority are deflected toward the east, running northeastward instead of northward. On the accompanying map it will be noted that Johnson creek runs northeastward for 15 miles. Oak Orchard for nearly the same distance, and most of the minor streams reaching the lake between Johnson creek and Eighteenmile creek have northeasterly courses. Other streams, like Sixmile and Hopkins creeks and the west branch of Twelvemile, are made up of reaches alternating northward and northeastward in direction, reminding one of the drainage lines among folded rocks which alternately follow and cross the strike. The east branch of Eighteenmile creek has for 7 miles a southwest course parallel to the northeasterly courses of other creeks.

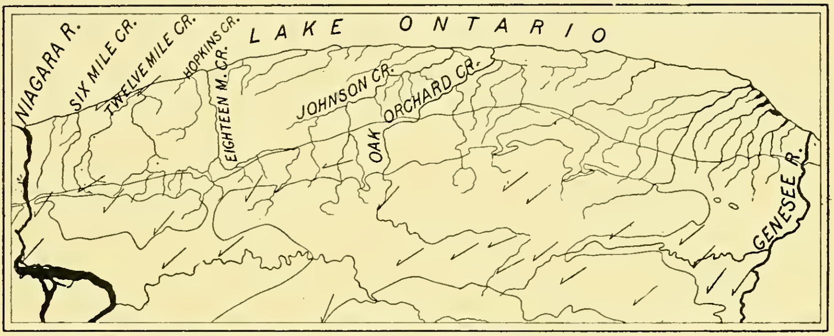

Figure 6.—*Drainage Map in western New York.*

The area represented measures 75 by 31 miles. The smooth lines are contours at 400, 600, and 800 feet above tide. The southern boundary of the Medina shale lies between the 400-foot and 600-foot contours. Arrows show the direction of ice motion as recorded by striæ and drumlins.

Some of these peculiarities were noted by Hall, who suggested control by a system of rock fissures,* but this explanation is unsatisfactory, as the general trend of joints in the district is due east and west.

In these days of accepted glacial theory, when the idea of topographic modification by ice is familiar to all, glacial action readily suggests itself in explanation of anomalies of drainage, and the working hypothesis with which I entered the field was that of control by ridges of drift. It was already known that a lobe or deep current of the ice-sheet followed the Ontario basin from east to west, spreading southward in such a way

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* Geology of Fourth District, p. 435.

as to produce striæ gradually curving from west to south, and the peculiarities of drainage under consideration were seen to fall into this general scheme of trends.

Only a few days of close observation were necessary to show that the drift-ridge hypothesis was inadequate, and it was finally abandoned for all the Medina plain except a tract in Monroe county near the Genesee river. The principal facts leading to its abandonment are connected with the depth of the drift. If the creeks were guided by ridges of drift the general depth of drift should be greater in the interstream tracts than under the stream valleys, but the reverse of this obtains through nearly the whole district of peculiar drainage. Along the creeks running ning northeast the drift mantle is relatively thick; between them it is relatively thin.

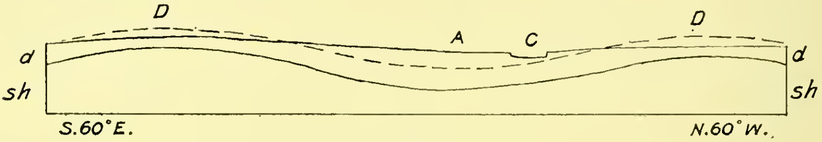

Figure 7.—*Diagrammatic Section of glacial Furrow and Ridges.*

sh, shale of the Medina formation. *dd*, drift. *DD*, region of sub-lacustrine degradation. *A*, region of sub-lacustrine aggradation. *C*, creek valley. The dotted line shows original profile of glacial drift.

The greater part of the surface was flooded by the glacial lake Iroquois, and that lake had an important influence on the topography, not merely silting up hollows with its sediments, but washing till from the hills and ridges and reducing the whole surface to a gently undulating plain. This plain is so even that the faint ridges by which the drainage is actually controlled are hardly discernible by the eye. Where the drift was eroded by the agitation of the lake water only its finer material was removed, the boulders being left, and the regions of greatest lacustrine degradation are represented at the present time by tracts of stony land, whose unfortunate owners, after utilizing the boulders as far as possible in the making of fences, construct great cairns from the surplus without seeming to exhaust the supply. This accumulation of residuary boulders is distinguished from bouldery till by the fact that it is only superficial. At a depth of 2 or 3 feet the evidence of concentration ceases, and the till below is but moderately stony. In a few localities the layer of boulders rests directly on the red shale, and the remnant of finer drift is too small for profitable culture. In belts of lacustrine aggradation, on the other hand, the soil is stoneless clay or sand, or sometimes gravel. and the drift is deeper, often so deep that the farmer's well does not reach its base.

From these facts it appears that if the drift were wholly removed and the rock surface bared the topography would comprise a series of ridges and troughs running parallel to the trend of the northeasterly streams. The details of rock configuration conform to the direction of ice motion, and are evidently products of glacial erosion.

The depth of the furrows is not definitely known, but some of them exceed 40 feet. Measurement was largely dependent on the facilities afforded by surface wells, and these do not completely traverse the drift in the deeper furrows. The significant fact is that throughout a considerable area the preglacial topography, presumably including a system of shallow valleys descending northward, was obliterated, and a radically different system of valleys was wrought. This could hardly have been accomplished without a general reduction of the surface to the extent of 40 or 50 feet, and the amount may have been considerably greater. The amount was surely greater in the vicinity of the Niagara river, where erosion, as already mentioned, not only carried the outcrop of the chief sandstone ledge back to the line of the Niagara escarpment, but removed so much of the underlying shale that the sandstone outcrop now contours the face of the escarpment for some distance above its base.

The failure of the glacial furrows to control the courses of Eighteenmile creek and Niagara river is due to local conditions. At each of these points the lowering of glacial lakes to the plane of lake Iroquois was accompanied by a stupendous torrent pouring over the Niagara escarpment,* and the detritus thus borne northward helped to silt up the glacial furrows of the plain. The subsequent lake action completed the work of gradation, so that when Iroquois was drained away these two streams found lines of continuous descent before them and chose direct courses to lake Ontario.

SUMMARY

The ice left the broad plateau of firm Niagara limestone with little modification. The cliff at its northern edge was somewhat worn, but its position not materially changed. The resistant ledges north of the Niagara limestone were worn back so far as to lose the contours typical of subaerial erosion. The topography of the Medina shale was reconstructed, its system of stream valleys and interstream ridges being replaced by glacial fluting on a large scale. While the Niagara escarpment antedates the period of glacial sculpture, ice erosion rendered it

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* Bull. Geol. Soc. Am., vol. 8, p. 286.

more prominent by excavation along its base and by the general degradation of the lowland it overlooks.

The district exhibits a marked contrast between the extent of erosion from a broad mass of limestone on the one hand and a broad mass of shale on the other, the ratio being, roughly, as 1 to 10 or 1 to 20.

ANTICLINE AT THIRTYMILE POINT, NEW YORK

Portion of level uplifted block shown at left of anticline. Lower part of overturned fold shown in upper right-hand corner

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DISLOCATION AT THIRTYMILE POINT, NEW YORK

BY GROVE KARL GILBERT

(Presented before the Society December 30, 1898)

CONTENTS

OBSERVATIONS

On the shore of lake Ontario, 30 miles east of the mouth of the Niagara river, is a bluff point on which a lighthouse stands. The waves are there actively engaged in eating back the shore, and their work has produced a cliff about 20 feet high, exhibiting red shale of the Medina formation, with a thin cover of drift. The shale is of variable texture, some of its layers being so arenaceous as almost to deserve the name of sandstone. The strata lie nearly horizontal, except at one place. At the apex of the cape is a fractured anticline, and this is accompanied by a vertical dislocation of 6 feet, the uplift being on the northeast side. The axis of the disturbance trends northwest and southeast, and the outline of the coast is such that the disturbance reappears in the bluff about 200 feet to the eastward. There was also at the time of my visit a third point of exposure, where the waves had reached the zone of fracture and developed a small cave.

Figure 1 gives a section of the anticline at the point of best exposure, and its character is further shown in plate 12. The disturbed zone diminishes downward, as though terminating or changing to a simple fault a short distance below the exposure. At the top the anticline is overturned toward the right, or southwest, a feature to be more fully described presently. At the base of the section observation is cut off by the shingle of the beach, but evidence of disturbance reappears at a distance of a few rods beneath the water of the lake, where beds of the same formation show an anticlinal structure, and this structure was traced as far from the shore as the bottom could be observed without the aid of a boat.

Where the dislocation reappears toward the southeast in the lake cliff there is no anticline, but instead a monoclinal flexure, descending from the uplifted mass at the northeast to the undisturbed mass at the southwest.

Above the cliff the general slopes of the land are gentle, presenting the subdued contours of a ground moraine. From this even surface there rises a low but unmistakable hill coincident in position with the anticline (see figure 2). This indicates that the dislocation occurred after the deposition of the till, for a ground moraine does not ordinarily reflect such topographic details on its surface.

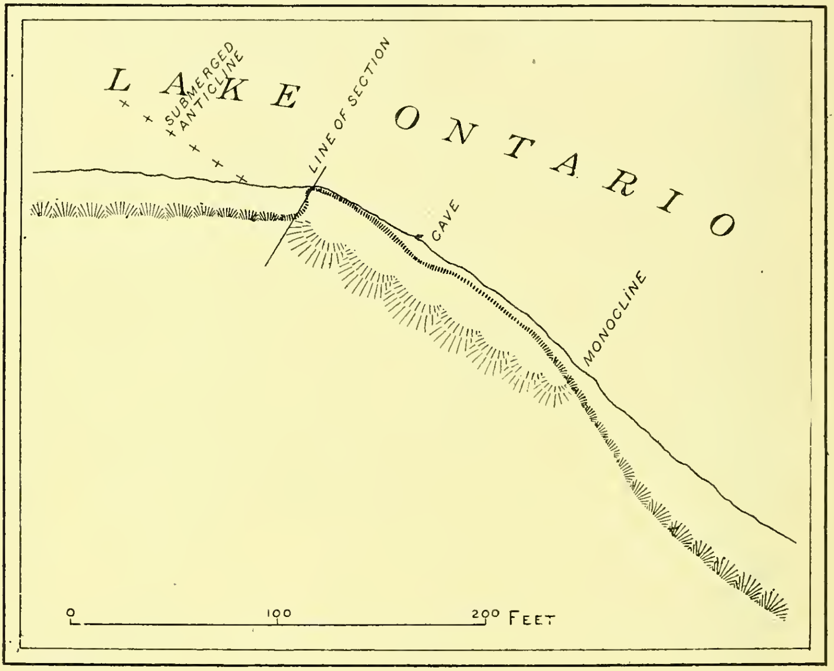

FIGURE 1.—*Sketch Map of Thirtymile Point.*

Showing relations of anticline and associated ridge or terrace to the shore and shore cliff of lake Ontario.

As already mentioned, the upper part of the anticline is overturned toward the southwest. In the natural section its outlines are somewhat indefinite, because the fractured rock is not readily discriminated from the surrounding till, composed chiefly of the same material; but it is clear that portions of the anticline pass beyond the vertical and are supported by the enveloping till.

INTERPRETATIONS

With reference to questions of cause, two features of the overturning are specially significant: one, that the overthrow is restricted to the part projecting above the surrounding rock; the other, that the crest is thrown toward the southwest, or in the direction of the local movement of the Pleistocene ice-sheet. These peculiarities point to the glacier as the cause of the overturning, and the deformation is thus distinguished from the ordinary anticlinal ridges of the old lake bottoms, which are clearly subsequent not only to the ice-sheet but to the glacial lakes.

On the other hand, the disturbance can not have been preglacial, for in that case ice erosion would have destroyed the projecting rock ridge. Indeed, the preservation of this frail ridge of crushed rock, and of the still softer ridge of till, shows that there was little ice scour after the dislocation occurred.

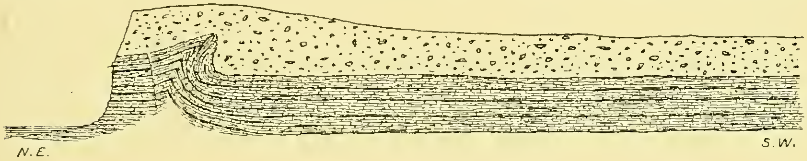

FIGURE 2.—*Section at Thirtymile Point.*

Showing anticline in Medina shale and associated ridge or terrace of till. For position, see preceding figure. The cliff at left is 20 feet high.

The only assumption as to time which seems to accord with all the facts dates the deformation just before the ice at this locality ceased to move. The edge of the glacier stood here when the uplift took place, there was enough subsequent motion to overturn the projecting anticline, and then the ice stopped or its face was melted back.

The association of the disturbance with the ice margin leads naturally to the further hypothesis that the glacier was responsible for all the phenomena—that the forward thrust of the glacier was able, under the critical conditions obtaining at the ice margin, to tear from its secular moorings a broad mass of rock and slide it a few feet forward and upward. If that is what actually occurred the slidden block was at least 300 feet broad and 20 feet thick, and its dimensions may have been very much greater.

An alternative hypothesis connects the dislocation with the general fault system of the region—if its trivial slips may be dignified by that title. In general the shale shows no trace of disturbance, its small southward dip being barely perceptible, but within 20 miles of this locality I have noted 10 small faults or groups of faults. With a single exception they belong to the thrust class. The hade ranges from 0 to 60 degrees, and the vertical displacement from 2 to 20 inches. In 5 instances the upthrust block moved southward, and other directions were southwest, west, and east. With some of the faults are associated local dips not exceeding 10 degrees. The faults are believed to be preglacial. The crucial evidence on this point—their relation to the ice-planed top of the rock mass—was not obtained, but they have the smooth walls characteristic of deep-seated shear-planes instead of the ragged faces ordinarily associated with superficial fractures.

It is conceivable that compressive strains such as caused these small faults accumulated under the ice-sheet and found relief at its retreating margin in the production of the Thirtymile Point dislocation. The ice-margin would be a critical line for such strains, as they would be there reinforced by strains arising from the horizontal thrust of the glacier.

The second hypothesis encounters a quantitative difficulty. If a dislocation of 20 inches is the greatest associated with the diastrophism of all the periods from Silurian to Neocene, a dislocation of 6 feet seems an excessive product of Pleistocene diastrophism; but this difficulty is mitigated by the fact, shown by shorelines of glacial lakes, that the region was subject during the ice retreat to differential uplift involving warping and straining.

The first hypothesis is of interest to glacialists because of its bearing on the question of the efficiency of the glacier snout as a plow. If the ice could loosen and push along a hill of firm shale, it would seem competent to crowd weak strata of clay and marl into such a chaotic heap as is exhibited by the Marthas Vineyard Cretaceous.

Should this description rouse enough interest to induce others to examine the locality, their visits should not be long delayed. This part of the coast is specially exposed to the attack of storm waves and is rapidly beaten back. The fractured anticline is a zone of weakness, and the attack is there peculiarly effective, so that after a very few years nothing will remain of the present features of dislocation except the subaqueous traces of the anticline.

FIGURE 1.—GIANT SAND-RIPPLE

Occurring in upper sandstone lens of the Medina formation at Lockport, New York, exposed in old quarry west of the Indurated Fiber Works

FIGURE 2.—GIANT SAND-RIPPLE

Occurring in "quartzose sandrock" of the Medina formation, exposed in the Niagara gorge, one mile above its mouth. New York Central railroad track in the foreground

GIANT SAND-RIPPLES

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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RIPPLE-MARKS AND CROSS-BEDDING

BY GROVE KARL GILBERT

(*Presented before the Society December 30, 1898*)

CONTENTS

Giant Ripples of the Medina

The Medina formation consists chiefly of red shale. In the type district, about Medina, New York, the thickness is about 800 feet, and there are beds of sandstone in the upper hundred feet. Most of the sandstones are argillaceous and soft, but there are a few lenses comparatively free from clay. These are usually white or gray, and afford a strong, durable stone, extensively quarried for structural purposes.

From some quarries flags and blocks of large dimensions can be obtained, but others yield only small and irregular blocks, because the rock is traversed by cross-bedding. The oblique structure is of a peculiarly intricate type, often exhibiting dips toward all points of the compass in the same quarry, and associated with it are many unconformities. There are places in the floor of the Whitmore quarry at Lockport where the strike of a dipping layer can be traced through an elliptic arc, like the end of a spoon, for 150 degrees, the dip swinging with the strike. There are places where oblique partings of opposite dip are seen in section to unite at the top, making angular anticlines, and other places where they unite below, making smoothly curved synclines.

Studying these structures in the summer of 1898, I was at first greatly puzzled, but at last became satisfied that they are phenomena of sand-rippling, differing in no respect except size from the familiar ripple-mark of the bathing beach and the museum slab. The anticlines and synclines are crests and troughs of sand-ripples, the cross-bedding is a result of deposition during the maintenance of a rippled surface on the ocean bed, and the unconformities record the readjustment of the sand-ripple pattern when the controlling water movement assumed a new direction.

In width (distance from crest to crest or trough to trough) these giant ripples range from 10 to 30 feet; in height, from 6 inches to 3 feet. Their material is a sand of medium grain. Their exposure in complete form is comparatively rare, but the cross-bedding with which they are constantly associated is exhibited in a majority of the visible sections of the sandstone lenses between the Niagara river and Medina, a distance of 33 miles. In Lockport they are found in lenses of three different horizons, and the opportunities for examination are excellent. They are also well exhibited in the principal sandstone ledge at Lewiston, the ledge named by Hall "the Quartzose Sandrock."

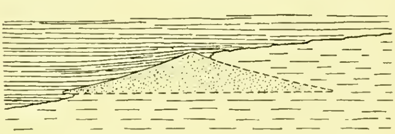

FIGURE 1.—*Section of Prism of Sandstone.*

The locality is 2 miles east of Pekin. The sandstone is represented in the diagram by a dotted pattern; the enclosing shale by lines. Broken lines distinguish the inferred part from the visible portion of the section.

Figure 1, in plate 13, shows an exposure in a small disused quarry on the south bluff of Eighteenmile creek, in Lockport, near the Indurated Fiber works. It includes two crests and an intervening trough. The depth of the trough is 29 inches, and its width (from crest to crest) 23 feet. Figure 2, plate 13, shows a trough fragment laid bare by the side-hill cut of the New York Central railroad in the gorge of the Niagara river. The portion observed measures 15 feet across and 16 inches in depth, but neither of the limiting crests remains. A larger pattern is indicated by a crest and part of the adjacent trough seen in a ravine about 2 miles east of the village of Pekin (figure 1). A triangular prism of sandstone 3 feet high, embedded in shale, has been partly bared by the cutting of the ravine. Its form and relations show that it is a detached crest of the sort produced when the supply of sand is not sufficient for the modelling of the fully developed ridge. In such cases the sand is gathered in a series of windrows corresponding to the crests of fully formed ripples (see *b*, in figure 2). As the ordinary ratio of width to height in sharp-crested fossil ripple-marks is 10 to 1, the thickness of this prism implies a ripple width of 30 feet or more.

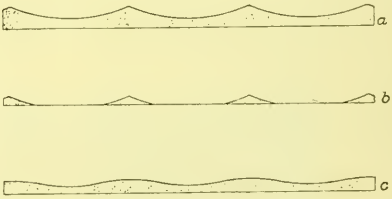

FIGURE 2.—*Typical Profiles of Sand-ripples.*

a, the ordinary form with angular crests. *b*, imperfect development of form *a* when the supply of sand is small. *c*, rounded form supposed to be derived from *a* by subsequent gentler agitation of the water.

Another example of great size was observed in the north part of the area worked over by the Whitmore quarries at Lockport. A solitary crest of the broad, low type (*c*, figure 2) exhibits a convex profile for about 15 feet. In ripples of this type the concave portion of the profile is usually as wide as the convex, and we again have an estimate of 30 feet as the approximate maximum width of the ripples.

Interpretation in Terms of physical Condition

If fully understood, these giant ripples should tell us something of the local physical conditions at the time of their formation, and some suggestions on this point are afforded by the theory of sand-rippling as at present developed. Previous to 1882, ideas as to the origin of water-made sand-ripples were crude and unsatisfactory. In that year an important paper was published by A. R. Hunt,* and two years later the results of three other investigators, C. de Candolle,† F. A. Forel,‡ and G. H. Darwin,§ appeared. While these contributions did not build up a complete theory, they left the subject in so satisfactory a shape that there has been little subsequent discussion.

The following summary statement outlines the present condition of the theory, without attempting to distribute to individuals the credit for their several shares.

A current of water flowing over a bed of sand reacts on any prominence of the bed. An eddy or vortex is created in the lee of the prominence, and the return current of this vortex checks traveling particles, causing a growth of the prominence on its downstream side. At the same time the upstream side is eroded, and the prominence thus travels downstream. It is a subaqueous dune. Its upstream slope is long and gentle; its downstream slope is short and steep. Such dunes have a moderate tendency to develop laterally, and they interfere with one another to some extent if they approach, but they do not develop a regular pattern with equal interval. They are rarely preserved as fossil.

The ordinary ripple-mark of beaches and rock faces is produced by the to-and-fro motion of the water occasioned by the passage of wind waves. During the passage of a wave each particle of water near the surface rises, moves forward, descends, and moves back, describing an orbit which is approximately circular. The orbital motion is communicated downward, with gradually diminishing amplitude. Unless the water is deep the orbits below the surface are ellipses, the longer axes

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* Proc. Roy. Soc. London, vol. 34, p. 1.

† Arch. Sci. Phys. et Nat., Geneva, vol. 9, p. 241.

‡ Arch. Sci. Phys. et Nat., Geneva, vol. 10, p. 39.

§ Proc. Roy. Soc. London, vol. 36, p. 18.

being horizontal, and close to the bottom the ellipses are nearly flat, so that the water merely swings forward and back. It is in this oscillating current, periodically reversed, that the sand-ripples are formed. A prominence occasions vortices alternately on its two sides, and is thereby developed in a symmetric way, with equal slopes and a sharp apex. There is a strong tendency to produce the mole laterally into a ridge, the space between ridges is definitely limited by the interference of vortices, and in time there results a regular pattern of parallel ridges, equally spaced.

It has been found experimentally that by varying the amplitude of the water oscillation, and also by varying its frequency, the size of the resulting ripples can be controlled; but the precise laws of control have not been demonstrated. Evidently the frequency of the natural oscillation equals the frequency of the wind waves, and its amplitude is a function of the size of the waves and the depth of the water; so that a relation will ultimately be established between wave-size, wave-period, and water-depth as conditions and ripple-size as a result.

Experiment has also shown that certain combinations of amplitude and frequency of water oscillation yield currents too feeble to mold sand into ripples, and certain other combinations yield currents too violent. When these limiting combinations have been discussed with reference to the combinations occurring in nature, the formula for ripple-size may be found to involve only two conditions instead of three.

Until that general law has been worked out no very satisfactory interpretation can be given to the giant ripples of the Medina sandstone; but as its formulation may be indefinitely delayed, I shall base a tentative interpretation on such fragmentary data as are available. Observations by Hunt and de Candolle show that large wind waves produce larger sand-ripples than do small waves. Some observations of my own on the bed of lake Ontario show that for moderate depths the size of ripples is not very sensitive to variation of water depth. The investigations of J. Scott Russell and others indicate that the amplitude of the oscillation of the water near the bottom is never greater than the height of the corresponding surface waves. In certain experiments Darwin found the width of sand-ripple about half as great as the amplitude of the simultaneous water oscillation. If these facts and inferences may properly be put together, they give a chain connecting the height of wind waves with the width of the ripple-marks they may produce, and indicate that at the most the ripple-marks are only half as broad as the waves rolling above them are high.

Should this tentative law be substantiated by future research the geologist may infer from the structure of the Medina sandstones that the

Medina ocean was agitated by storm waves sixty feet high. As great waves require broad and deep bodies of water for their generation, such a result would demonstrate the association of the Medina formation with a large ocean.

Associated Cross-bedding

The relation of sand-ripples to cross-bedding was studied first in the quarries exhibiting the giant ripples, and afterward, to better advantage, on the beach of lake Ontario, where blocks of sandstone, smoothed by beach-rolling, exhibit small ripple-marks and the associated oblique structures in every variety of combination and section.

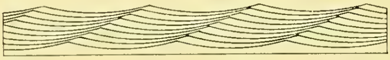

Figure 3.—*Cross-bedding produced by slow Shifting of Ripple System during Deposition.*

It appears that sediment may be added to a rippled surface without any disturbance of the pattern, but that there is usually a coincident, gradual bodily shifting of the pattern in some direction. In order that sediment may be brought it is necessary that there be a general current in addition to the oscillating current caused by waves, and it may be safely assumed that the shifting of the ripple pattern follows the direction of this general current. Just as the direction of the general current may make any angle, or no angle, with the direction of the oscillatory movement, so the direction toward which the pattern is shifted may bear any relation to the trend of the ripples. The shifting of the ripple profile during the accumulation of sediment makes the accumulation unequal on the two sides of the trough (figure 3), and if the ratio of shifting to deposition exceeds a certain amount, there is deposition on only one side of the trough and erosion on the other (figure 4). In each case an oblique structure or cross-lamination results, and in the second case the general structure given to the sand mass includes two systems of oblique planes. One system is produced by deposition, and the laminæ represent the successive positions of the concave ripple profile. The other system is produced by erosion, and its planes represent the progress of the profiles of the troughs along certain tangents. This structure, which was frequently observed, may be called compound cross-bedding. The tangent planes are sometimes so gently inclined that they might easily be confused with true bedding. They are broadly exhibited in quarry floors at Lewiston and Lockport.

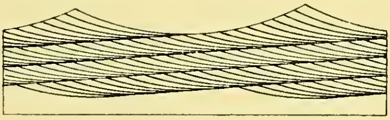

Figure 4.—*Compound Cross-bedding produced by Deposition and partial Erosion associated with shifting Sand-ripples.*

On part of the floor of the Whitmore quarry at Lockport the ripple pattern seems to have been a reticulation, including oval troughs, and deposition associated with a current parallel to the trough axes produced the spoon-shaped layers previously referred to. Such reticulated patterns, supposed to be caused by two systems of waves, either simultaneous or successive, are often observed on a smaller scale.

When waves from a new direction act on a surface already rippled they produce a new pattern which at first combines with the old one but eventually obliterates it. The troughs of the new pattern are formed in part by excavation from ridges of the old, and the lamination associated with the old ridges is truncated so that the new lamination is unconformable (see figure 5). Where the ripple pattern is small several unconformities of this chraacter may appear in a hand specimen, and where they occur on a large scale in the quarries of the Medina sandstone they make a complexity of structure greatly impairing the value of the stone for architectural purposes.

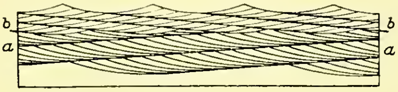

FIGURE 5.—*Complex Cross-bedding and Unconformities associated with Ripples.*

A change in the direction of the water waves superposes the compound cross-bedding *b-b* on the compound cross-bedding *a-a*.

It is proper to add that I do not regard sand-rippling as a general or even frequent cause of the cross-lamination observed in rocks, except on a small scale. In some of the quarries of the Medina sandstones there is cross-lamination without any indication of associated rippling, and I am satisfied from personal observation that the conspicuous cross-lamination exhibited in certain quarries of the Berea sandstone at Elyria and Amherst, Ohio, as well as the superlative cross-bedding of the Juratrias sandstones of Utah, Arizona, and New Mexico, were formed in some other way.

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ARCHEAN-CAMBRIAN CONTACT NEAR MANITOU, COLORADO

BY W. O. CROSBY

(Read before the Society December 28, 1898)

CONTENTS

INTRODUCTION

While studying the sandstone dikes accompanying the great fault of Ute pass in the summer of 1896, my attention was naturally attracted to the contact between the granite and the overlying sedimentary rocks, which, as every geological visitor to the region must know, is admirably exposed in the district immediately north of Manitou, on both sides of Ute pass. I was deeply impressed, as would be any student of New England geology, by the wonderful clearness and continuity of the exposures, but more especially by the almost absolutely plane form of the contact thus disclosed, and having since enjoyed an opportunity to make a more particular examination of this contact, I am more than ever convinced that it represents a type of erosion unconformity which, although probably of frequent and widespread occurrence in nature, is somewhat unique in geological literature, or at least has not received hitherto the attention which it merits.

The only particular reference to the granite-sedimentary contact of the Manitou district which I have noticed is by Hayden.* In describ-

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* Ann. Rep. U. S. Geol. and Geog. Surv. of the Territories, 1873, p. 35.

ing the Williams Canyon section, he says: "The sedimentary beds fill up in a remarkable manner the inequalities of the original surface of the metamorphic rocks." Later* Hayden published an illustration of the Williams Canyon contact which is reproduced here (figure 1). It certainly tells a very different story; but having read the statement of 1873 before my first visit to Manitou, I concluded that the illustration had been selected simply to show a clear unconformity, and was not to be considered representative as to details. I anticipated, therefore, a repetition of the phenomena of the Boston basin, where the basal Carboniferous strata fill marked depressions and even crevices in the granite surface (figure 2), which is fully comparable in ruggedness with that which the granite presents on the same coast today. I was thus wholly unprepared

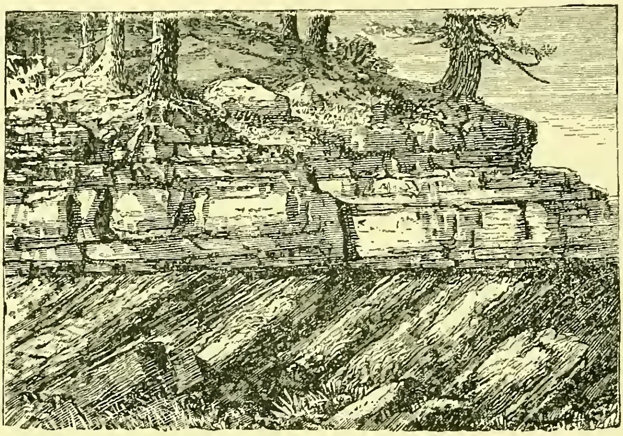

FIGURE 1.—*Cambrian Sandstone in Williams Canyon, Colorado* (Hayden).

The sandstone rests unconformably on gneissoid granite.

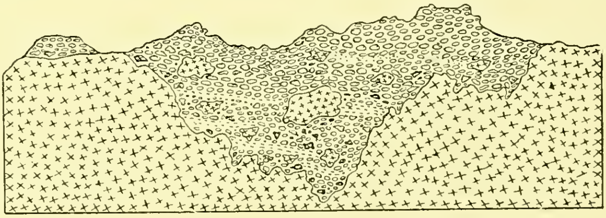

FIGURE 2.—*Carboniferons Conglomerate, Nantasket, Massachusetts.*

The conglomerate fills an erosion hollow in granite. Scale, 1 inch = 10 feet.

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* Ann. Rep. U. S. Geol. and Geog. Surv. of the Territories, 1874, pl. 6, fig. 2.

to find the sedimentary rocks on the flanks of the great Front or Rampart range of Colorado, in Williams canyon and elsewhere, resting on a granite surface almost as smooth and flat as a floor and in striking contrast with the existing granite topography of that region. Hayden's illustration, after all, is representative of the entire area and a far better expression of the essential facts than his verbal statement. The actual facts suggest interesting possibilities in the way of erosion and the development of peneplain surfaces in early times, and suggest also a brief comparison with the facts of other regions to determine whether the phenomena really are as unique as they appear to be on first sight, and an inquiry as to the cause or essential conditions of such extraordinarily plane erosion. Having thus indicated the scope of the present paper, I turn to a presentation of the facts of the Manitou area.

GENERAL STRUCTURE OF THE MANITOU EMBAYMENT

The Manitou embayment of sedimentary rocks lying in the angle between the granitic rocks of the southern end of the Front range on the north and the similar rocks of the Pikes Peak massif on the south embraces from below upward, as described by Hayden, Cross, and others—

1. A basal sandstone which is usually 40 to 50 feet thick, white or gray for the lower 10 to 15 feet, and dull red or brown above, only rarely of arkose character, but frequently more or less glauconitic.

2. This sandstone, which may be referred provisionally to the Cambrian, becomes calcareous upward, passing into red, cherty limestones, and these into a massive gray limestone having a thickness of several hundred feet. The limestones are throughout more or less magnesian and contain recognizable traces of a Lower Silurian (Ordovician) fauna.

3. This great Manitou limestone series is overlain without apparent unconformity by the Fountain (Carboniferous) beds, 1,000 to possibly 1,500 feet in thickness—a remarkable complex of red and white arkose sandstones, grits, and conglomerates.

4. The red sandstone series (Triassic), 1,000 feet or more in thickness.

5. The white, variegated and gypsiferous Jurassic strata.

6. The Cretaceous series, beginning with the massive and conspicuous Dakota sandstone.

As the accompanying map* (plate 14) shows, these formations are cut off on the southwest by the Ute fault with its sandstone dikes, while to the northwest the sedimentaries are seen to lie at low angles directly on the granitic rocks, the highly irregular erosion outline of the embayment in this direction, in striking contrast with the straight southwest

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*Adapted from Hayden: Ann. Rep. U. S. Geol. and Geog. Survey of the Territories, 1874, p. 40.

margin, owing its lobate character wholly to the topographic relations, since the strata naturally extend farther up the slope of the mountains on the ridges than in the valleys. The third or eastern boundary of the embayment, which may be regarded as a triangle extending from Camp creek on the north to Bear creek on the south, with its apex in Ute pass, is well marked by the outcrop or hogback of the vertical Dakota sandstone. The three sides of the embayment are thus (southwest) a profound obliquely transverse fault,(east) a precipitous monocline or possible longitudinal fault, and (northwest) the intersection of the basal beds or Cambrian sandstone by a highly irregular erosion surface, and it is with this lobate northwest margin that we are now specially concerned.

North of the embayment, along the base of the Front range, the prevailing strike is north-south and the dip easterly, the lower terranes usually sloping gently away from the granite, while the Red beds (Triassic) and higher formations plunge steeply down beneath the plains. The embayment has its origin in the Ute fault, a drop along an oblique fracture equal at least to the combined thickness of the entire Paleozoic and Mesozoic terranes. This has bent the beds around to a northeast-southwest strike and southeast dip, and, as before, the dip is moderate (10 to 30 degrees) below the base of the Red beds and steep above. Along the southwest margin, however, each formation is in turn abruptly upturned to a steep northeast dip by the drag of the Ute fault. In fact, at some points along this line the beds are overturned to a high southwest dip, as we should naturally expect, since the great fault belongs in general to the reversed or overthrust type, with a hade to the upthrow side (southwest) of 5 to 45 degrees.

Archean-Cambrian Contact

Of the two granite or Archean borders of the embayment, one (southwest) is secondary and abrupt, marking a profound displacement, while the other (northwest) is original—the gently sloping floor on which the sediments were deposited. The granite is the coarse and (superficially) red biotite granite so characteristic of the region and remarkable for its extensive surface disintegration. It is cut occasionally by dikes or irregular masses of a finer granite, in which the biotite is less prominent, and it exhibits at some points, as in Williams canyon, a marked gneissoid structure, with a relatively basic or even dioritic facies.

The general character of the Cambrian sandstone, the basal member of the sedimentary series, has been indicated. According to Peale,* it embraces in Glen Eyrie, from below upward, coarse grayish white sand-

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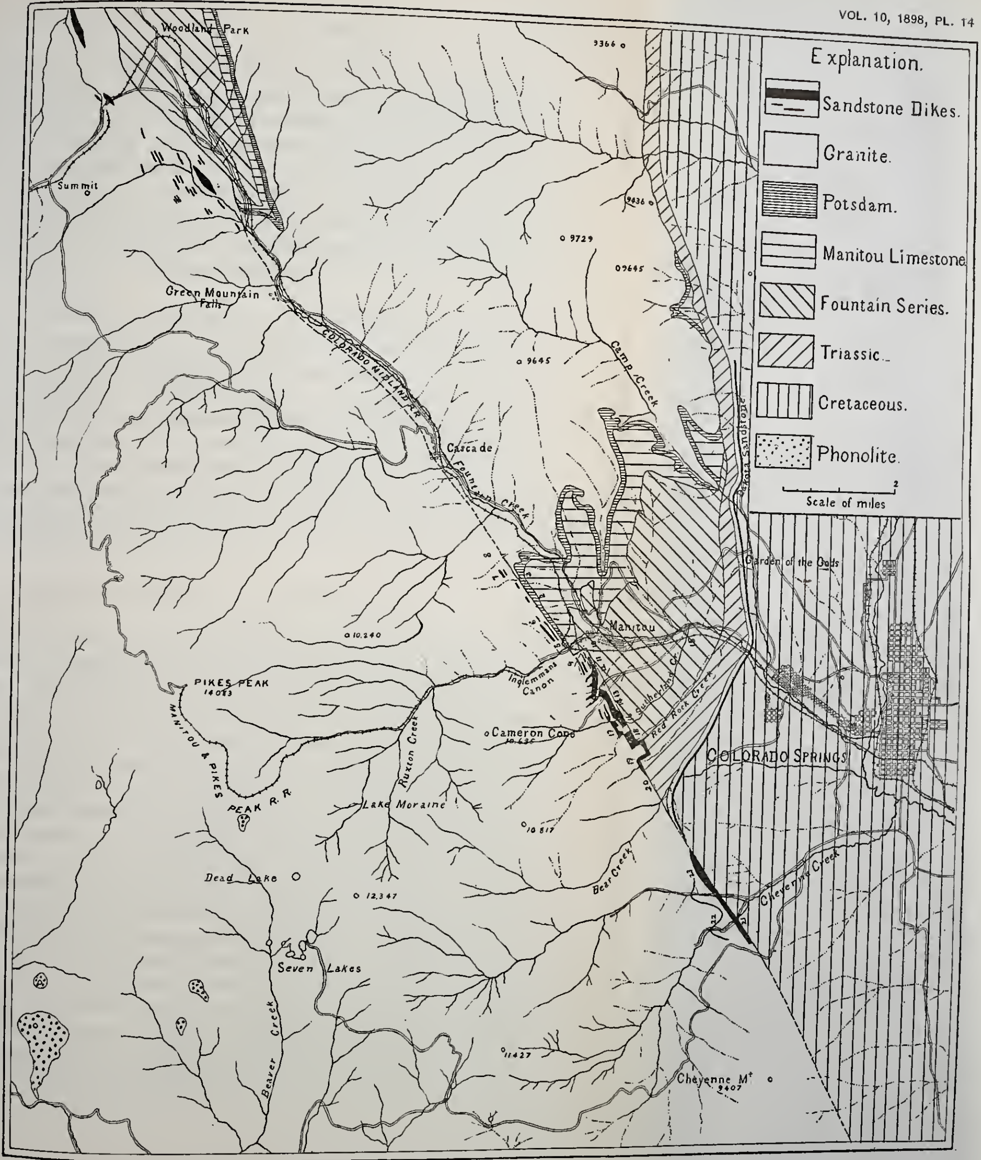
* Ann. Rep. U. S. Geol. and Geog. Surv. of the Territories, 1873, p. 201.


Summit



GEOLOGICAL MAP OF THE MANITOU EMBAYMENT

stone, 20 feet; coarse dark green (glauconitic) sandstone, 4 feet; coarse gray sandstone, 6 feet; brick-red sandstone, with green (glauconitic) layers, 20 feet; total, 50 feet. The arkose character so noticeable in some of the sandstones higher up in the sedimentary series of the Manitou embayment, and especially in the Fountain (Carboniferous) beds, is almost entirely wanting in the Cambrian, even where it rests directly on the granite. Although the sandstone is, in the main, rather coarse, it is rarely conglomeratic. On or near the granite it sometimes encloses a few small pebbles, but these are almost invariably vein quartz and well rounded or water-worn.

The best general views of the contact are obtained by the traveler through Ute pass, between one and three miles above Manitou, on both sides of Fountain creek, as shown rather unsatisfactorily in the two accompanying illustrations (plates 15 and 16). The best view of all is one looking eastward from the Colorado Midland railroad, but not represented by the photographs. It is also well exposed for observation in Williams canyon, as already noted, and in Queens canyon, above Glen Eyrie. In all of these general views the actual exposures of the contact have a good degree of continuity, and the successive exposures are seen to lie almost absolutely in one plane.

Structural Details of the Contact

In going up Ute pass by the wagon road we come, in less than a mile from the junction of Ruxton and Fountain creeks, to the point where the contact crosses Fountain creek. On the right is a quarry in the glauconitic (red and green) upper part of the Cambrian; and on the left the contact is well exposed in a lateral gulch, shown in plate 15, on the right, opposite the bend in the road, the quarry being on the left just around the bend. Farther up the gulch, near the railroad, which is not shown in the picture, the exposures of the contact are very clear and continuous, the white basal member of the Potsdam resting on a plane smooth surface of the granite. A few small and well rounded quartz pebbles are seen in the sandstone along the contact, but no granite pebbles, although 5 feet above the contact the sandstone shows an occasional line or trace of granite debris—grains of quartz and red feldspar. North of this gulch and immediately above Fountain creek, as seen in the upper right-hand side of plate 15, the almost plane contact is admirably exposed, and the exposure continues around the end of the hill northward to the south side of the next gulch, where the granite has been worn out along the contact, leaving the gray sandstone projecting, unsupported, 10 to 20 feet as a smooth, flat ceiling dipping south 15 to 20 degrees. From this gulch the line of contact, exposed only at intervals and dipping 10 degrees to the east and southeast, curves to the north and west around a high hill to the point where it is cut off by the Ute fault. At two points

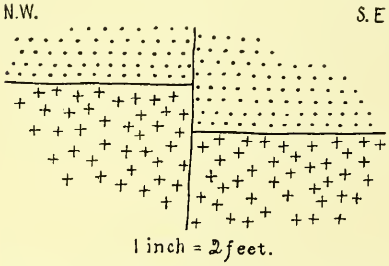


Figure 3.—*Contact broken by a Gravity Fault.*

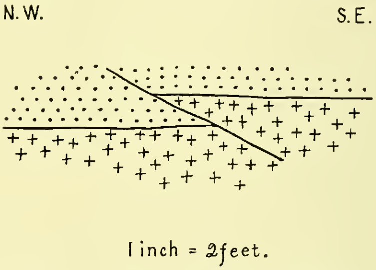


Figure 4.—*Contact broken by a Thrust Fault.*

on the west side of the hill the contact is seen to be broken by minor but very clear faults (figures 3 and 4).

Returning to the east side of Fountain creek, the contact is found to be well exposed on the south side of the small gulch between the quarry and Rainbow fall, where it is involved in a sharp inverted flexure (figure 5) accompanied by obliteration of the bedding of the sandstone. Toward the left (east) end of the upper limb of the fold the contact is broken in a way (figure 6) to suggest both faulting and shearing, with injection of the gray sandstone into the broken granite, and thus throwing light on the formation of the sandstone dikes. The exposure here trends east-

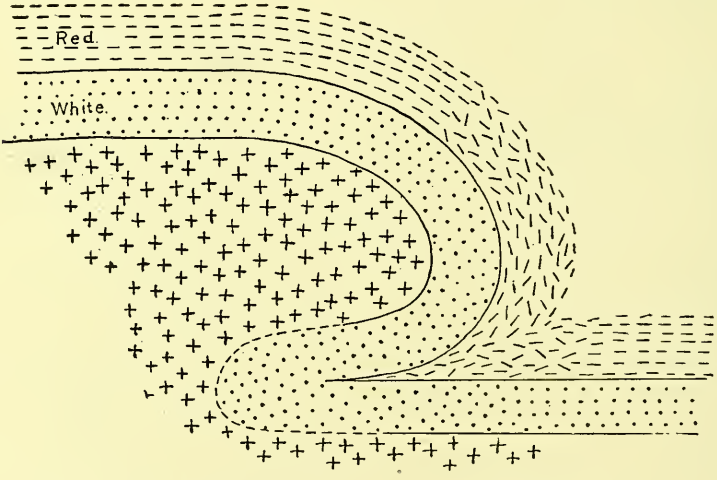


Figure 5.—*Overthrust Flexure of basal Cambrian Beds on East Side of Ute Pass.*

VIEW IN UTE PASS, COLORADO, LOOKING SOUTH

Showing contact of granite and Cambrian sandstone on the right and less distinctly on the left

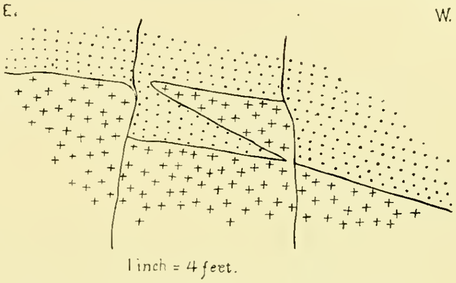


FIGURE 6.—*Faulting and Shearing of the Contact.*

west; but higher up it turns to a general north-south direction and follows the western slope of the high, sharp ridge (plate 16) separating Fountain creek and Williams canyon. The upper part of this ridge is composed of the Manitou (Silurian) limestone, in which the subterranean drainage of past ages has excavated the Grand cavern and cave of the Winds. For the first quarter of a mile along this slope the contact, with the normal southeast dip of 10 degrees, is exposed almost continuously, and is almost absolutely plane, showing no appreciable sags, faults, or breaks of any kind, and crossing great dikes of fine granite in the normal coarse granite without deviation, the granite, regardless of its structure, having been worn down to a plane surface. Farther north along this ridge the contact is mostly concealed by slide and talus (plate 16), but in the vicinity of the Grand cavern several original erosion irregularities of the contact were observed (figures 7, 8, and 9).

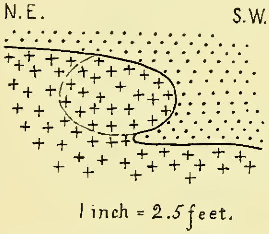


FIGURE 7.—*Erosion Irregularity of the Contact.* Due to spheroidal form in the granite.

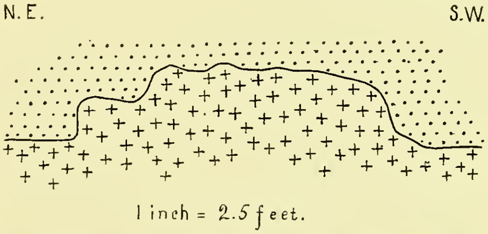


FIGURE 8.—*Residuary Hummock of the Granite Surface.*

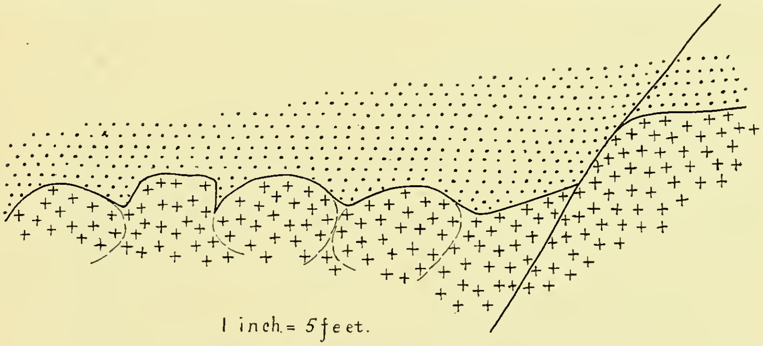


FIGURE 9.—*Irregular Contact broken by a Fault.*

Between the limestone ridge and Fountain creek are four outliers of the Cambrian sandstone capping hills of granite—two north and two south of the carriage road to the Grand cavern—affording admirable exposures of the contact. The two southern and smaller outliers are clearly on the north-south axis of the overthrust fold described above (figure 5), and in the second one, from the south especially, the Cambrian beds are very sharply flexed upward on the east side. It is obvious that the east side of Ute pass is here marked by a sharp monocline dipping west, pitching south, and dying out northward, and probably developed as a series of faults in the granite. On the south side of the second outlier is a clear oblique and reversed fault of the contact (figure 10), which is evidently connected with the sharp upward flexure of the beds.

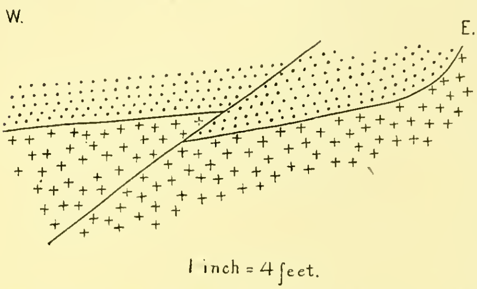


Figure 10.—*Contact modified by a Thrust Fault and Flexure.*

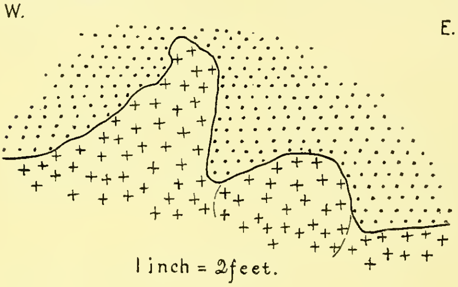


Figure 11.—*Angular Erosion Irregularity of the Contact.*

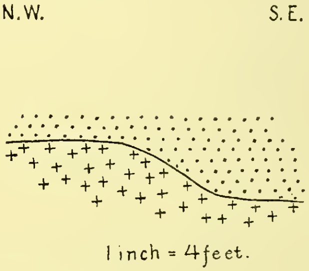


Figure 12.—*Slight Erosion Irregularity of the Contact.*

North of the road to the Grand cavern, at the extreme southern end of the third outlier, which has the normal southeast dip of 5 to 10 degrees, is a very marked irregularity of the contact (figure 11), which is evidently original, as shown by the welding

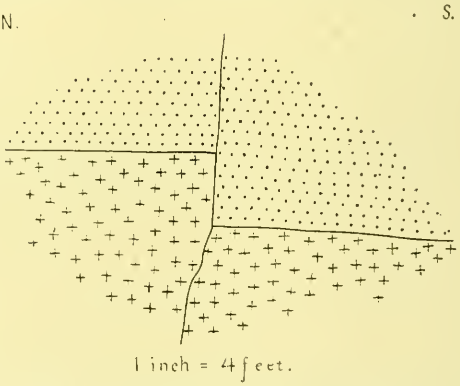
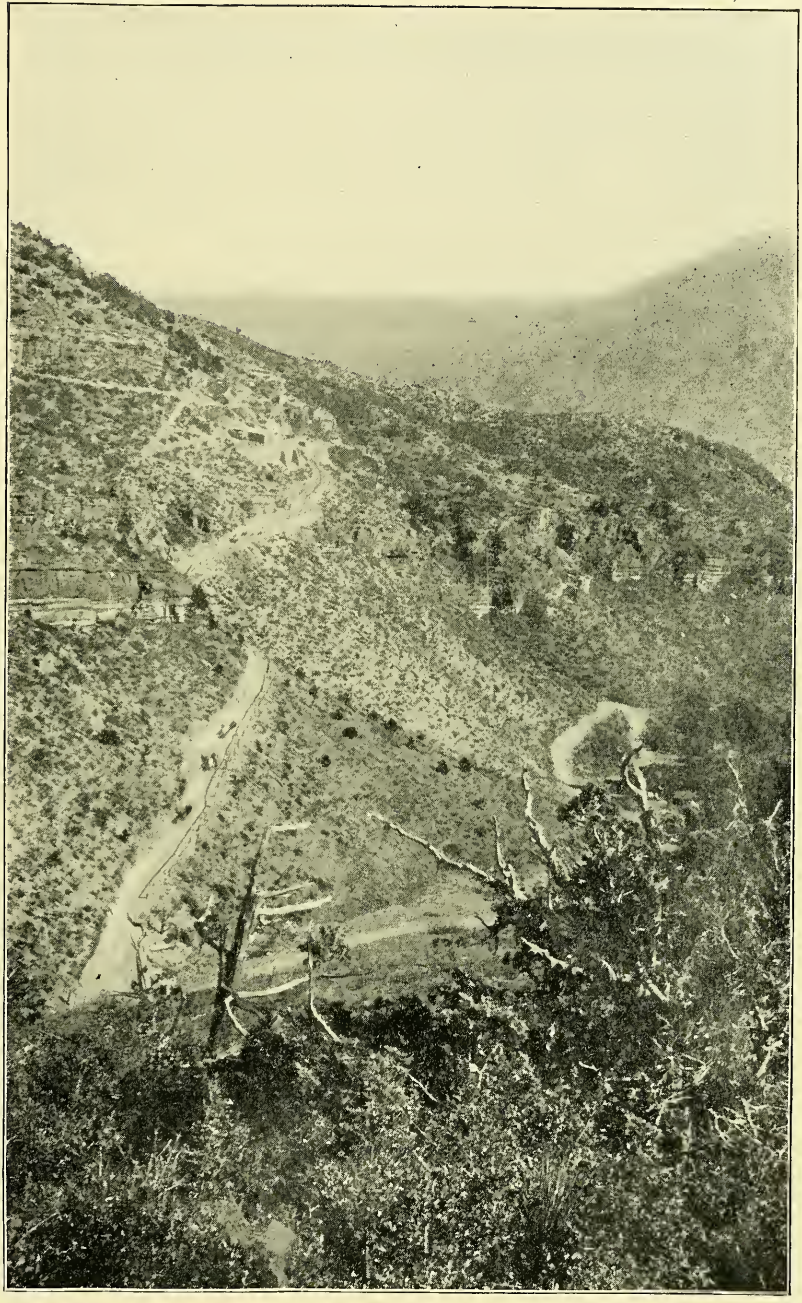


Figure 13.—*Contact broken by a Gravity Fault.*



VIEW ON ROAD TO MANITOU GRAND CAVERN, COLORADO

Showing contact of granite and Cambrian sandstone, partly concealed by slide and talus

of the sandstone and granite and the adaptation of the lines of deposit in the sandstone to the outline of the granite. Near the middle of the west side of this outlier is a little fault (figure 13), and near the north end another original irregularity (figure 12). With these exceptions the contact, which is not exposed on the east side of this outlier, is a nearly perfect plane along the entire west side, several hundred feet in length.

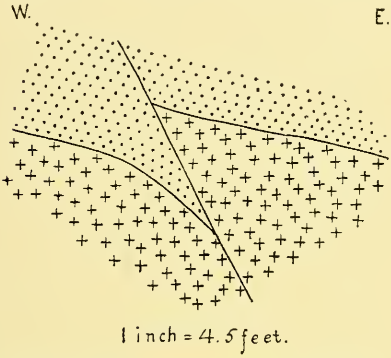


FIGURE 14.—*Contact broken by a Fault with reversed Flexure.*

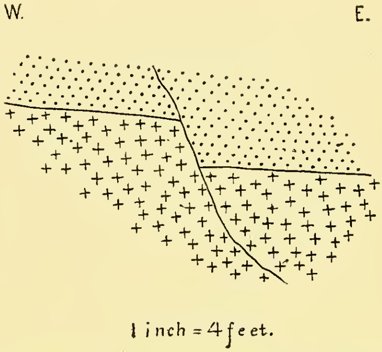


FIGURE 15.—*Contact broken by a Gravity Fault.*

The fourth and largest outlier, immediately behind the camera in plate 16, shows on the south side, from east to west, first a reversed fault, with a flexing of the sandstone and contact contrary to the apparent movement (figure 14). The sandstone is slickensided along the fault. Fifty feet west of this are two compensating slickensided faults of the

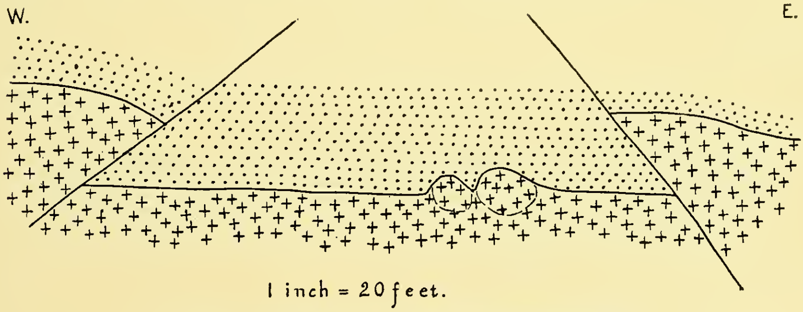


FIGURE 16.—*Contact broken by compensating Thrust Faults.*

same general type (figure 16), and only requiring greater throw to make of the included sandstone a good sandstone dike. The original irregularity of the contact between these oblique slips is clearly due, as in many other cases, to an apparent concretionary structure in the granite, developed in some cases as a tendency to concentric exfoliation, showing that in Cambrian time this structure existed, as now, and influenced the erosion of the granite. These rounded and in general more resistant masses, as now exposed in the granite, vary from 1 to 6 feet in diameter.

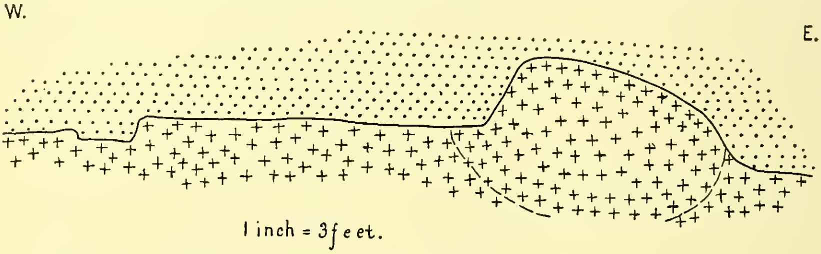


FIGURE 17.—*Residuary Hummock of the Granite Surface.*

Due to spheroidal structure.

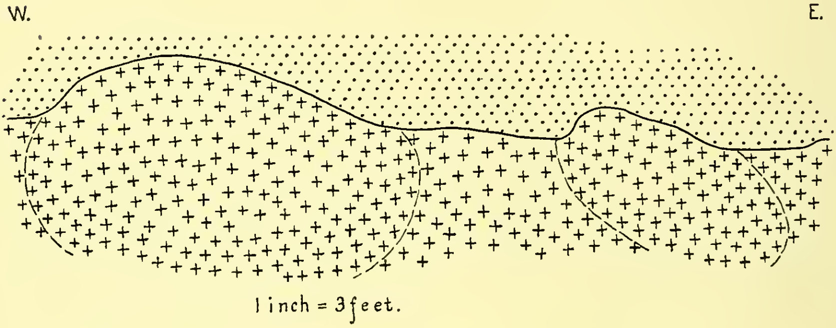


FIGURE 18.—*Residuary Hummocks of the Granite Surface.*

Due to spheroidal structure.

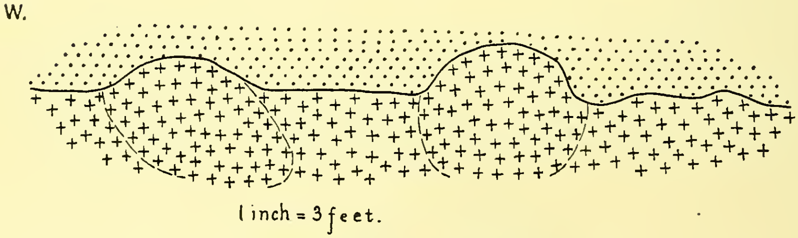


FIGURE 19.—*Structure similar to Figure 18.*

They were usually left in relief on the eroded surface, but were sometimes worn out to form hollows. Forty feet farther west is a small normal fault (figure 15), and 40 feet farther still an original irregularity (figure 17). Then after 20 feet the contact is broken by a small vertical fault, with segregation of quartz along the fault in the sandstone. Forty feet beyond this is an original irregularity due to two large concretionary masses in the granite (figure 18), which is repeated on a smaller scale 50 feet farther west (figure 19), and 15 feet from the west end of this cliff one concretionary mass is clearly seen resting on another (figure 20).

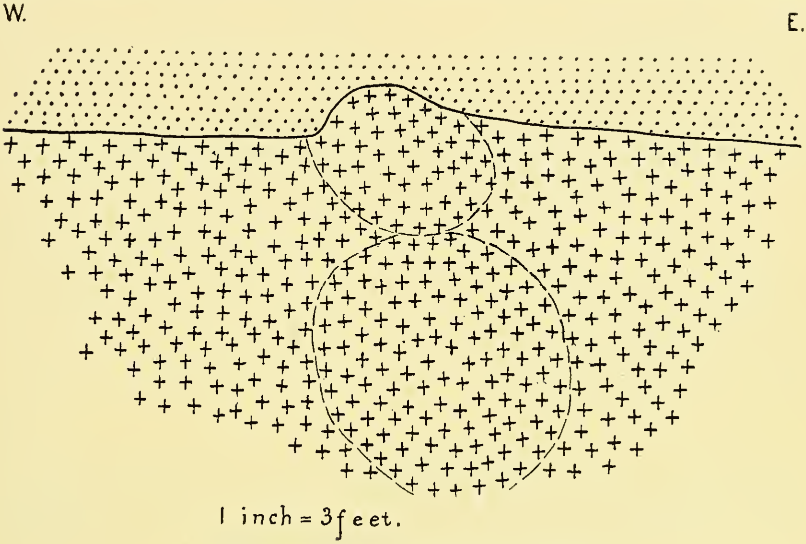


Figure 20.—*Erosion Irregularity of the Contact.*

Due to superposed spheroidal forms in the granite.

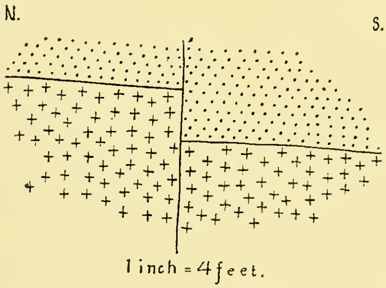


Figure 21.—*Contact broken by a Gravity Fault.*

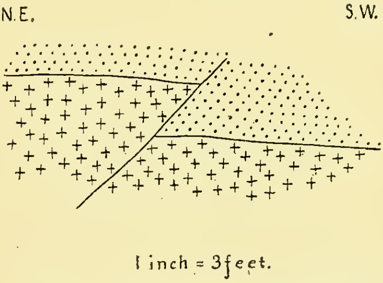


Figure 22.—*Contact broken by a Thrust Fault.*

Going north along the west side of the outlier we observe first three small faults (figures 21, 22, and 23), the last one occupied by a veinlet of quartz. Immediately beyond this, in the middle of the west side, the contact is complicated by two large, flat lenses of granite (figure 24), one entirely and the other nearly enclosed by the sandstone, and probably indicating complex oblique faulting before the consolidation of the sandstone, the enclosed sand forming now, virtually, a sandstone dike. Farther on the contact drops irregularly about 4 feet (figure 25). This is probably not a fault, but one of the most marked of the original irregularities of the granite surface. The spheroidal structure is admirably developed in this part of the granite. Continuing toward the north end of the outlier, we have first two faults (figures 27 and 28), and near the reversed fault the sandstone is well slickensided. Then comes an original inequality due, apparently, to the wearing or weathering out of one of the spheroidal masses of granite (figure 26). A general view of this west cliff shows toward the north end a sharp upward flexure of the contact (figure 29). This is a less extreme example of the same type as the

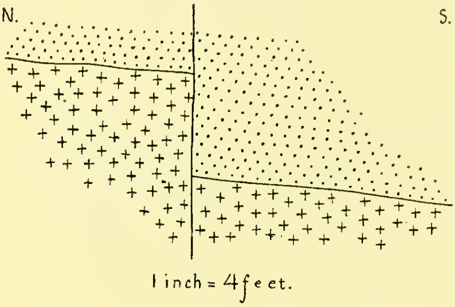


Figure 23.—*Contact broken by a Gravity Fault.*

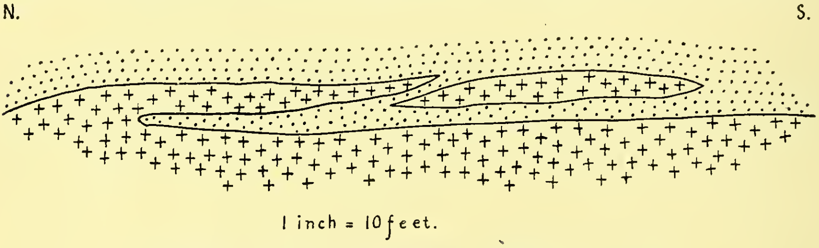


Figure 24.—*Probable oblique Faulting and Shearing of the Contact.*

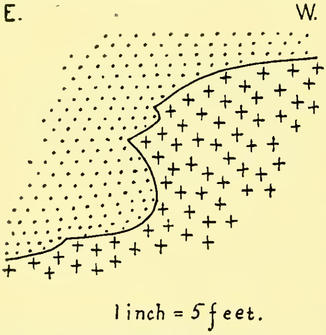


Figure 25.—*Small Erosion Scarp of the Granite Surface.*

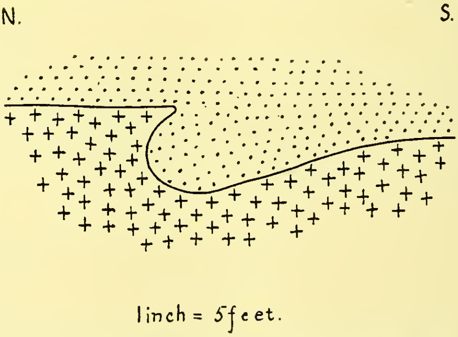


Figure 26.—*Original Depression of the Granite Surface.* Due to erosion of a spheroidal mass.

flexure in the cliff south of the outliers (figure 5, page 146). The contact is not clearly exposed on the north and east sides of this hill, nor around the north end of the ridge between Ute pass and Williams canyon.

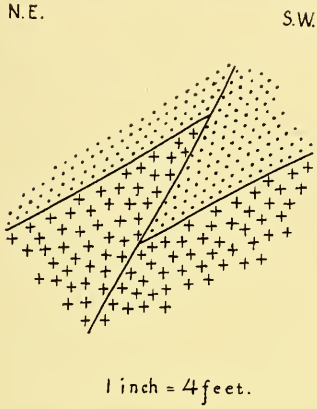


FIGURE 27.—*Contact broken by a Thrust Fault.*

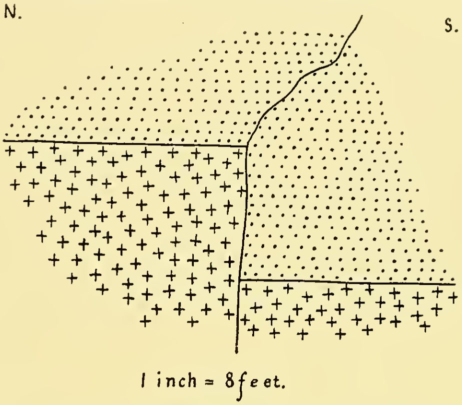


FIGURE 28.—*Contact broken by a Gravity Fault.*

Entering Williams canyon at the lower (southern) end, we pass between walls of the Manitou limestone; the glauconitic red sandstone (Cambrian) first appears at the Narrows, about half a mile from the mouth of the canyon; between two and three hundred feet beyond this we strike the top of the basal gray sandstone, and about the same distance farther brings us to the granite. The general or normal dip of the strata is about south-

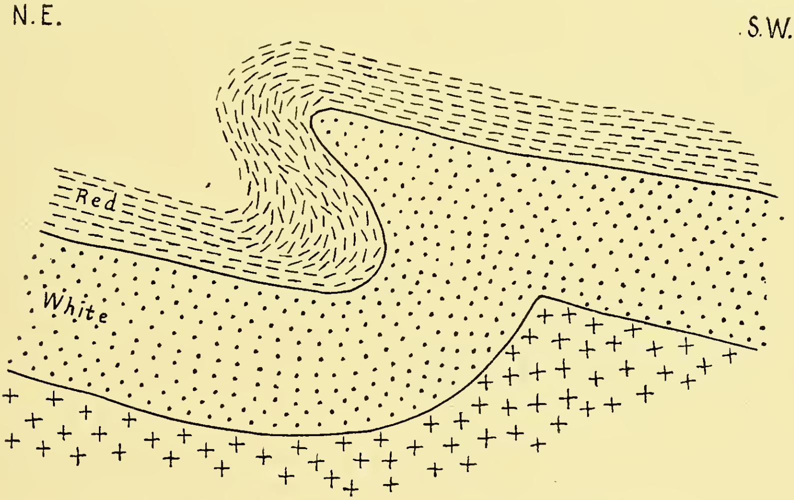


FIGURE 29.—*Overthrust Flexure of the basal Cambrian Beds in Fourth Outlier.*

east 15 degrees. The granite that first appears in the bottom of the canyon evidently forms a broadly rounded erosion boss nearly 100 feet in its north-south diameter, with the strata curving smoothly over it. A similar but somewhat smaller swell of the strata immediately south of this undoubtedly indicates another boss not quite uncovered. The granite shows here only on the west side of the road, so that the east-west profile of the boss must be rather abrupt (figure 30). The granite is bright red, of fine to medium texture, and, what is of special interest, the outcrop or boss shows more or less across its entire breadth, but particularly at the southern edge, a distinct conglomerate of granite fragments and pebbles (mostly well rounded) between the solid granite and the white sandstone. The sandstone forms the matrix or paste of the conglomerate, and the fragments of granite extend upward several inches in the sandstone. In fact, where most distinctly shown, the conglomerate appears to be about 2 feet thick, and the largest granite pebbles are perhaps 6 inches in diameter. They are very closely packed, and the conglomerate grades downward into the weathered joint structure of the granite, so that there is probably not more than 1 foot of true conglomerate.

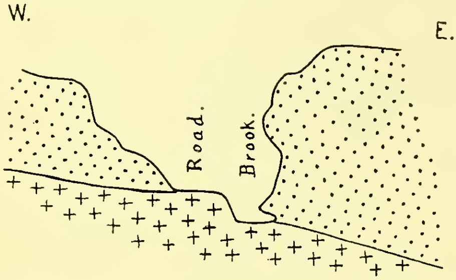


FIGURE 30.—*East-west Section of the Contact in Williams Canyon.*

North of this swell of granite the contact is exposed continuously for over 200 feet. It is broadly undulating, with often a trace and at one point fully a foot of granite conglomerate separating the granite and sandstone. The surface of the granite now descends below the level of the road for about one hundred feet, and then with broad undulations the

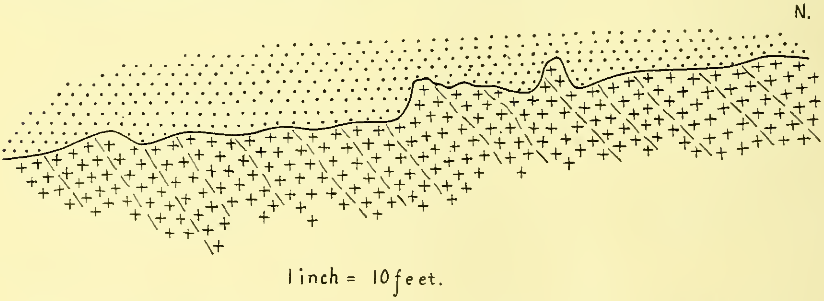


FIGURE 31.—*Irregular Erosion Contact of the Sandstone and gneissoid Granite in Williams Canyon.*

contact is exposed continuously for at least 500 feet to and beyond the point where the carriage road to the cave of the Winds turns to ascend the mountain. For the first 300 feet or so the granite is highly laminated or gneissoid, as shown in Hayden's figure (1, on page 142), the structure planes dipping north and northwest 30 to 60 degrees. There are only slight indications of conglomerate along this part of the contact, except the scattering small rounded quartz pebbles. The contact is not broken by any clear faults in the Williams Canyon section, the influence of the Ute fault apparently not extending so far to the eastward, and aside from the boss and the broad undulations of the granite surface, the original erosion irregularities are all on a minor scale. Figure 31 shows the contact on the west side of the road, on the southern slope of the boss. It is very clear that the stratification of the sandstone adapts itself to all these minor inequalities, filling hollows before it covers elevations, but it seems to curve regularly and evenly over the main swells of granite, although these, too, are probably original erosion forms. Continuing up the canyon, the granite, of varying characters, is exposed almost continuously, but the contact only rarely. On the east side, about a mile north of the carriage road, I noted the original irregularity shown in figure 32. The contact rises more rapidly than the bottom of the canyon, and crosses without satisfactory exposures the broad ridge or spur of the mountains between Williams canyon and Queens canyon, on Camp creek.

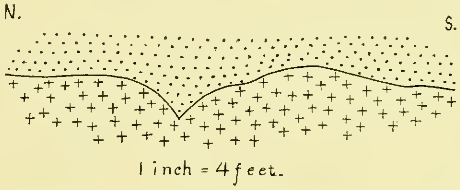


Figure 32.—*Original Erosion Hollow in the Contact Surface.*

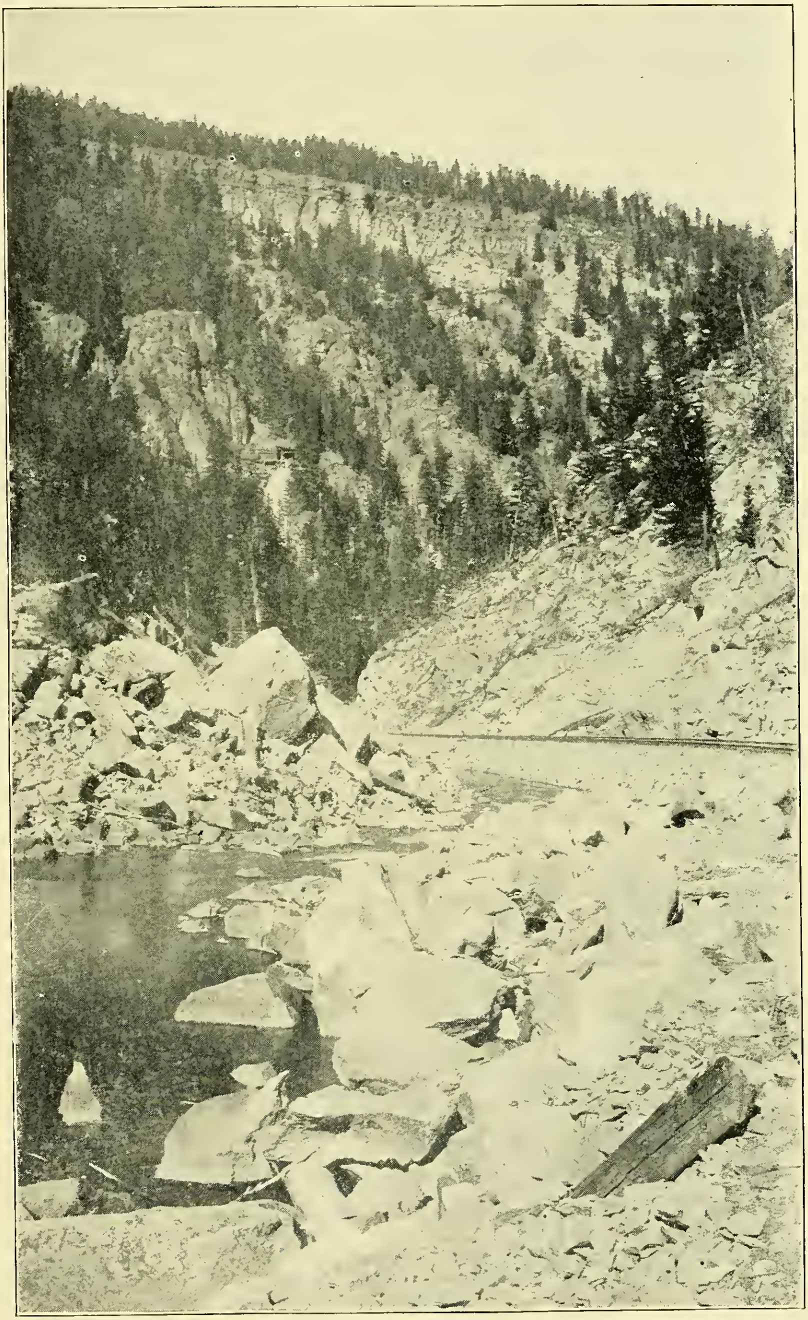
Going up Camp creek, the narrow passage through the Dakota hogback forms a gateway to the beautiful expansion of the valley in the vertical red beds known as Glen Eyrie, and the canyon proper begins with the Manitou limestone, dipping east or east by south 10 to 15 degrees. Conformably below the limestone we have the Cambrian sandstone, as described by Peale, resting on the granite, which is largely gneissoid. The contact is exposed almost continuously on the precipitous walls of the canyon for half a mile to a mile above Glen Eyrie, and as usual, it is almost devoid of relief features, one or two slight faults and several small hummocks due to concretionary forms in the granite being all that I could make out.

Summary of the structural Features of the Contact

The general views of the contact afforded by the canyons and the intervening ridges show conclusively that it is practically a plane for the entire Manitou area. The actual exposures, revealing every minutest detail, are absolutely continuous in some cases for hundreds and even thousands of feet and aggregate several miles in length, and the preceding notes faithfully describe all the irregularities of the contact I was able to make out in traversing these miles of exposures. The secondary irregularities, due to faulting and folding, are seen to be readily distinguished from the true original erosion hummocks and hollows, and eliminating the former, in imagination, we find the granitic and gneissic floor of the Cambrian sea to have been almost as featureless as a bedding plane of the sandstone deposited upon it. The specially startling fact is, of course, not the infrequency, but rather the small scale of the erosion inequalities. With the exception of the gentle undulations of the contact noted in Williams canyon, I have discovered no elevations or depressions departing more than 4 feet, and in only one instance (figure 25, page 152) more than 2 feet, from the general surface. Again, the inequalities, with unimportant exceptions, are hummocks and not hollows—erosion remnants and not channels, clearly marking the end and not the beginning of the process of baseleveling; and finally, such slight inequalities as survived the wearing down of the granite may in general be correlated with its coarsely concentric or spheroidal structure, showing that at the last the erosive action was highly discriminating, the spheroidal masses, like knots in a board, offering the greatest resistance to the planing process.

Comparison with other Regions

It has not been the writer's privilege to make a detailed study of the Archean-Cambrian contact elsewhere in the Rocky mountains, but general observations in other parts of this great region over which the Paleozoic strata present a surprisingly uniform section have convinced me that the contact phenomena of the Manitou district are certainly not unique, but probably widespread and characteristic. In the valley of Eagle river (plate 17) and in the canyon of Grand river, above Glenwood, Colorado, the contact between the granite and the white or gray sandstone at the base of the Cambrian is readily traceable for miles along the mountain side as a strongly marked straight and often horizontal line, with every indication that a detailed examination would reveal the same paucity of inequalities as in the Manitou embayment. My recollections of structural details in the Black hills of South Dakota are somewhat dimmed by the lapse of eleven years; but I recall that the contact of the Cambrian sandstone and the highly inclined Archean (or Algonkian ?) schists is often approximately plane, and among my photographs I find



EAGLE RIVER CANYON, COLORADO

Showing contact of granite and Cambrian sandstone

a view of the contact taken on Box Elder creek, on the east side of the Hills (plate 18). This suffices at least to show that irregularities, if not entirely wanting here, occur only on a very minor scale.

I have searched the literature of Rocky Mountain geology in vain for any detailed description of this important contact, which may without exaggeration be described as at once the most widespread, strongly accentuated, and deeply significant structure plane of all the trans-Mississippian region. It has been frequently referred to in general terms and figured diagrammatically, the figures being generally, like Hayden's, consistent with a highly plane or featureless Archean floor of the Cambrian sea. Several of the folios of the United States Geological Survey for Colorado, Montana, etcetera, show this contact in both maps and sections, but the texts and illustrations alike are wanting in details.

We are indebted to Walcott* for the best general summary of our knowledge of the Archean-Cambrian (not necessarily Potsdam) contact in North America. In the section on the surface of the pre-Cambrian land the original and quoted descriptions, wherever topographically explicit, indicate in general that erosion in each region had nearly or quite completed its task of reducing the land to a perfect baselevel before the deposition of the Cambrian sediments began.

In describing the Grand Canyon section of northern Arizona (figure 33), Walcott says:

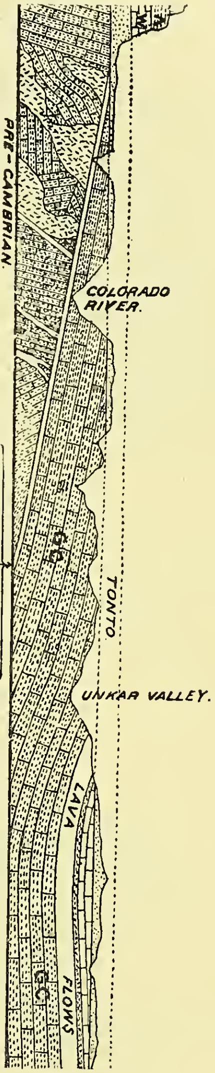


FIGURE 33.—*Grand Canyon Section* (Walcott).

Illustrating the plane unconformities between the Grand Canyon series (*G C*) and the overlying horizontal Tonto group (Cambrian) and the underlying, highly disturbed pre-Cambrian (Algonkian) rocks.

> "A baselevel of erosion appears to have been reached before the Cambrian rocks (Tonto group) exposed on the line of the canyon section were deposited. Both the Archean and Algonkian rocks were eroded nearly to a horizontal plane prior to the deposition of the Upper Cambrian sandstone. Here and

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*The North American Continent during Cambrian time, 12th Ann. Rep. U. S. Geol. Survey, pp. 523-568.

there a harder layer of lava or quartzite forms a low ridge, but as a whole the basal layers of the Cambrian were deposited upon a nearly level surface."

The accompanying figure, the more essential part of which is reproduced here, is in perfect agreement with the text, and shows a like unconformity between the Grand Canyon group (Unkar and Chuar) and the Vishnu group of the Algonkian. Both of these unconformities were also noted by Gilbert* (figure 34).

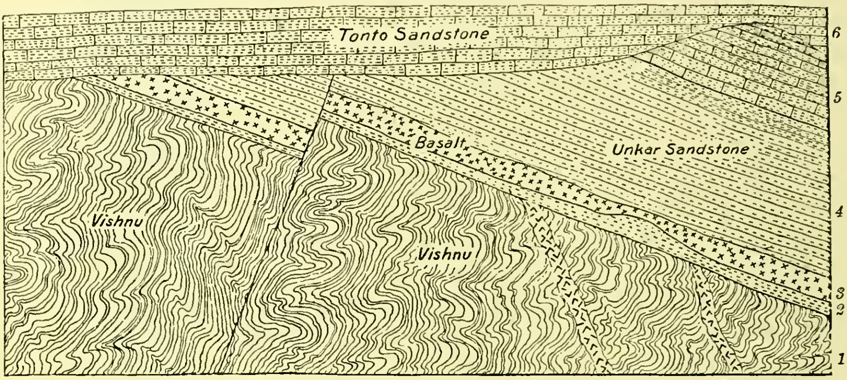

Figure 34.—*Section of North Side of Grand Canyon* (Gilbert).

Showing same unconformities as figure 33 and a pre-Tonto fault.

According to Walcott,† Packsaddle mountain, in Texas, exhibits a similar relation of the Algonkian and Cambrian strata (figure 35).

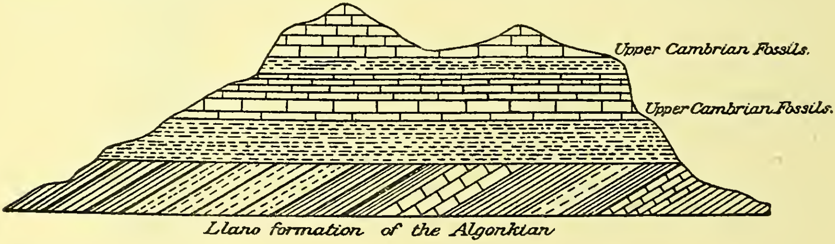

Figure 35.—*Section of Packsaddle Mountain, Texas* (Walcott).

Showing Cambrian strata resting unconformably on the Algonkian.

Irving‡ describes the pre-Potsdam (pre-Cambrian) land surface of Wisconsin as exhibiting, in the main, but gentle undulations.

"Looked at in greater detail, however, it is seen to have numerous minor and

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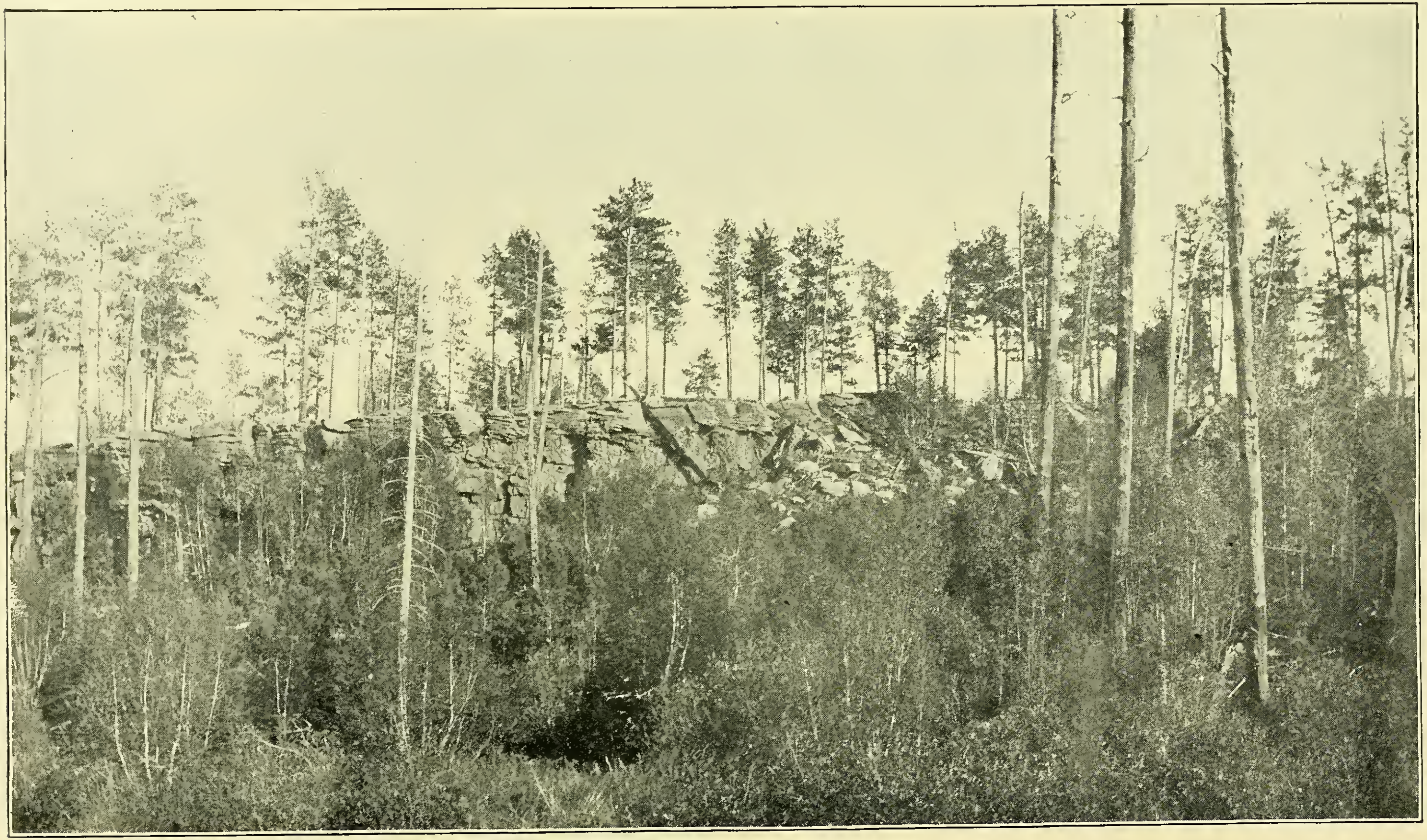
*14th Ann. Rep. U. S. Geol. Survey, p. 507.

†Am. Jour. Sci., 3d ser., 28, pp. 431-432.

‡7th Ann. Rep. U. S. Geol. Survey, p. 401.



VIEW IN THE BLACK HILLS, SOUTH DAKOTA

Showing contact of vertical Algonkian schist and Cambrian sandstone

often somewhat abrupt irregularities. The more abrupt of these have an evident genetic relation to the durability and general resisting power of the rocks which compose them."

He further states that these prominences, in exceptional cases, rise from beneath the Potsdam (Cambrian) sandstone to heights of from 100 to 600 and even, in the Baraboo ranges, of 1,200 feet. Irving's more general sections are reproduced in figures 36 and 37. Explicit descriptions are, of course, far more satisfactory than the highly generalized figures usually accompanying them, and the latter must be quoted and used cautiously.

Dr A. C. Lawson, on the other hand, concludes that the early Paleozoic rocks were laid down on a surface which did not differ essentially from that presented by the exposed Archean surface of the present day; but, notwithstanding this and similar statements from other good observers concerning the conditions in Canada, the Adirondacks, and other regions, the fact remains that the general consensus of opinion is emphatically in favor of the view that the Cambrian, and especially the Potsdam sediments of North America, were in general deposited upon a surface of pre-Cambrian rocks far more perfectly baseleveled than that presented by these older formations in any part of the continent today. All that can be claimed for the Manitou area, therefore, is that this almost universally flat contact has here one of its most perfect developments.

Subaerial versus Marine Erosion

Although the competency of subaerial erosion to develop a typical peneplain, as defined by Davis, is still questioned by

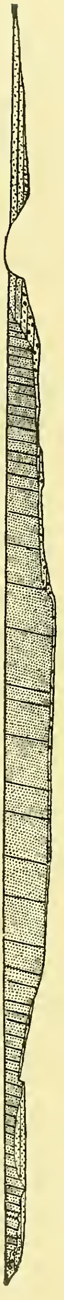


Figure 36.—*Section at upper Narrows of Baraboo River, Wisconsin.*

Showing unconformity between Potsdam (Cambrian) sandstone and Huronian quartzite (Irving).

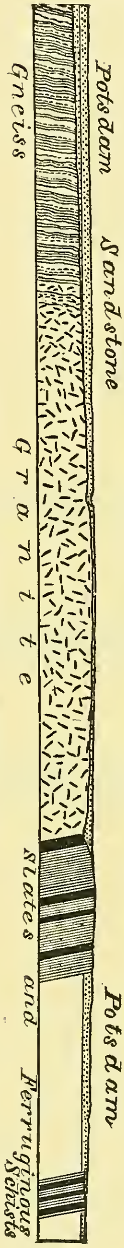


Figure 37.—*Section on Black River, Wisconsin* (Irving).

Showing Potsdam (Cambrian) sandstone resting on steeply inclined Archean rocks. Scale, 2 miles to the inch.

some, we may at least insist that a merely approximate plane is its utmost limit—a limit toward which it ever tends but which it can never pass; for the action of surface agencies, and especially of running water, must ever be differential, more concentrated and energetic on some areas than on others, and even the peneplain demands a degree of stability in the earth's crust which many are reluctant to concede.

On the other hand, marine erosion or the wearing away of the edge of the land by the waves and currents of the sea is, in the long run, differential only in regard to the varying character of the rocks—a limitation which, given time enough, may be completely overcome; and absolute stability of the crust is so far from being essential to the development of a plane surface that we may say that a slow movement of subsidence presents on the whole the most favorable condition. It is not then so much a baseleveling as a planing process. The subsidence constantly minimizes the task and permits the agent (the gnawing edge of the sea) to clear itself of the debris due to its own operation. Walcott's diagrams, reproduced in figure 38, convey the idea very clearly, and it is evident that given a rate of subsidence proportional to the hardness of the rocks the result may pass beyond the peneplain, yielding, theoretically at least,

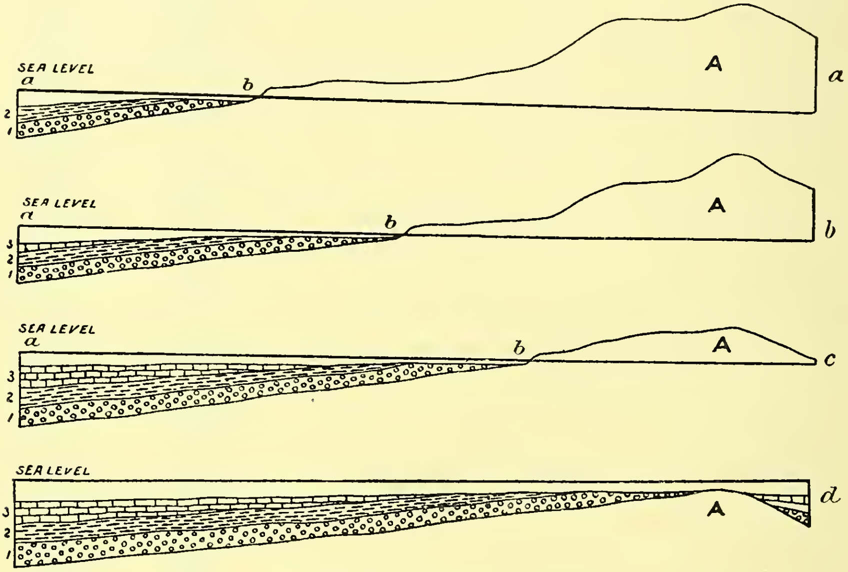


FIGURE 38.—*Diagrammatic Sections* (Walcott).

Illustrating deposition of sediments on a seashore which is being gradually depressed in relation to sealevel.

a surface entirely devoid of relief. This condition, so far as the unusually satisfactory evidence permits us to judge, is almost realized in the Manitou district, where the insignificant and almost inappreciable relief features occupy but a minute fraction of a surface which is otherwise hardly distinguishable from a perfect plane.

In reaching the conclusion that the sea has at least put the finishing touches upon and given character to a plane rock surface which may very well have been reduced to a peneplain by prior subaerial erosion, I am not unmindful of the view advanced by Hayes and Campbell* that this supplementary erosion may be due to chemical agents acting in the subaerial zone, or more specifically to the solution of silica by the azohumic acids of marshy tracts. But this argument appears to me inadequate and inconclusive, at least as an explanation of the continent-wide phenomenon under consideration, and the same may be said of the argument suggested by McGee's account† of sheetflood erosion in the arid districts of the west.

No one questions the invasion of the land by the sea in Cambrian times, or that, as Walcott and others have insisted, given time enough, the mill of the ocean beach was competent to grind the face of the continent to the nearly perfect plane now preserved in the Archean-Cambrian contact. Therefore it would seem illogical to endeavor to press into this service localized agencies whose very existence in Cambrian times is a matter of conjecture.

RELATION OF THE FORM OF UNCONFORMABLE CONTACTS TO THE CHARACTER OF THE IMMEDIATELY OVERLYING SEDIMENTS

Not only were the Archean granites of the Manitou area—alike the coarse and the fine grained, the massive and the gneissoid varieties—worn down by the surf of the Cambrian sea to a surface as smooth and flat, in the main, as a floor, but on this floor was left hardly a recognizable trace of the granite. In other words, the base, at least, of the Cambrian is very seldom in any appreciable degree of arkose character, and then, so far as I have observed, only in close proximity to some residual hummock where, we may suppose, the lateral gnawing of the waves went on to the last; and it may be noted in passing that the comparative abruptness of these slight residuary reliefs is far more consistent with marine than with subaerial erosion. With the exception of an occasional well rounded pebble of vein quartz, the basal member of the Cambrian is a nearly pure white quartz sandstone, usually of rather friable texture, but

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* Bull. Geol. Soc. Am., vol. 8, pp. 213–226.

† Bull. Geol. Soc. Am., vol. 8, pp. 87–112.

sometimes cemented to a firm sandstone or quartzite. Higher up, where it must have been deposited in deeper water offshore, it becomes more or less ferruginous and glauconitic and then calcareous; but the sandstone is throughout surprisingly free from feldspar and mica, the almost complete absence of arkose material being, as previously noted, the strongest point of contrast between the Cambrian and the sandstones of the higher formations. The Cambrian of the Manitou area is not unique in this respect, for its composition here accords perfectly with my observations in the valley of Eagle river and in the Black hills and with the published descriptions of the Cambrian throughout the Rocky mountain region and eastward to the Champlain valley and beyond. Thus Logan,* in describing the Potsdam (Cambrian) of the Saint Lawrence valley and the northern side of the Adirondacks, says:

> "The thoroughly rounded form of the grains of sand composing a large portion of the deposit, and the fact that all the material other than quartz has been bruised up and washed out from so much of it, would seem to make it probable that the formation accumulated slowly, and that the Potsdam [Cambrian] coast remained unchanged for a great length of time."

These two main facts—a plane erosion surface and the generally nonarkose character of the overlying sediment—must, then, be correlated as complementary phases of the erosion process and as testifying with equal distinctness to an extremely slow subsidence of the pre-Cambrian land beneath the Cambrian sea. In other words, the transgression of the sea, which, as suggested by Walcott, probably occupied the whole of Cambrian time, was so slow and gradual that erosion could, at most points, or save where the sea encountered rocks of exceptionally resistant character, like the Baraboo quartzite of Wisconsin, accomplish its most perfect work in all its phases—planation, reduction of the resulting debris to its simplest and final terms (quartz-sand and clay), and the thorough assorting of these products, so that the clay was deposited only in deep water remote from the shore along which the sand slowly accumulated.

Merrill† has covered this ground in part by suggesting a dual correlation of the arkose character of sediments with climatic conditions and the rate of deposition. According to the first, arkose indicates a predominance of disintegration over decomposition in the decay of rocks, and hence a dry or frosty climate, and, vice versa, the absence of arkose in sediments is indicative of decomposition as the dominant erosion factor, and hence a warm and humid climate. The alternative correlation implies that deposition may follow so closely upon disintegration as

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*Geology of Canada, 1863, pp. 108, 109.

†Bull. Geol. Soc. Am., vol. 7, p. 362.

to forestall decomposition. This must mean, however, that, as would doubtless be generally conceded, subaqueous are less favorable than subaerial conditions to the chemical decomposition of mechanical detritus, and suggests a sharper distinction than is commonly made in this connection between subaerial and marine erosion. The former yields, according to climatic conditions, arkose or non-arkose detritus, and the arkose detritus yields, according to the rate of deposition, arkose or non-arkose sediments. The essentially unaltered condition of arkose sediments in all geological formations proves that the process of kaolinization is practically at a standstill on the marginal sea-floor. Daubrée and others have shown, on the other hand, that the fine trituration of silicates, even in pure, cold water, is inevitably attended by liberation of the alkalies and alkaline earths and the formation of kaolin as the final residue. To summarize: arkose in sediments implies rapid deposition of mechanical detritus—the product of subaerial or marine erosion—and the absence of arkose is consistent with either slow or rapid deposition of the subaerial chemical detritus, or the slow deposition of mechanical detritus from any source; but it must always mean slow deposition for sediment in close proximity to an erosion unconformity, as is the basal member of the Cambrian sandstone, and then the unconformity should, theoretically, be of an approximately plane or baseleveled and featureless character.

Not only is the basal member of the Cambrian sandstone in the Manitou area almost absolutely free from arkose material, but it is also, as a rule, remarkably well assorted—mechanically pure as well as chemically pure—and evenness of grain does not here mean exceptional fineness of grain, although the sandstone usually becomes somewhat finer upward from the base. This even texture or mechanical homogeneity, expressed also in the practical absence of conglomerate and grit layers, is additional proof that the sedimentary process was deliberate and thorough, and it is probably a safe correlation, well sustained and illustrated by a comparison of the Cambrian and Fountain beds of the Manitou embayment, that arkose sediments are in general ill assorted, and vice versa. It may be noted, however, that to some extent a limitation upon the textural homogeneity of sandstones, through any considerable thickness, is imposed by the condition that below a certain size effective abrasion ceases, neither the size nor the angularity of the grains suffering appreciable diminution with continued trituration.

The gray to white color of the basal sandstone is believed to have a like significance, indicating not only the complete elimination of the feldspar and mica of the granitic debris, but also the removal by gentle and long continued attrition of the more or less distinct pellicle of iron oxide and clay, by which, as Russell* has shown, each grain of quartz in residuary earths, and to some extent in the regolith as a whole, is naturally invested. It is, of course, well known that this whitening of sands by the removal of the ferric oxide which coats and stains the grains may be accomplished through the agency of decaying organic matter, as may often be observed under vegetable mold and peaty deposits, the iron being reduced to soluble ferrous forms. But in the Manitou area, at least, it is only in that part of the Cambrian sandstone which is most unquestionably a beach deposit, and where the conditions during deposition must have been exceptionally favorable to the peroxidation and chemical fixation of iron, that the decolorization has occurred; and here organic matter or any indication of its former presence and iron oxide are equally conspicuous by their absence. The only satisfactory conclusion, therefore, is that, as suggested by Russell, the sands were bleached by mechanical attrition.

In deeper and more quiet water offshore, where the overlying reddish sandstone must have been deposited, enough red clay would also naturally have been deposited to fill the interstices between the grains and give the sandstone a ruddy tint in spite of the fact that the quartz grains, in passing through the mill of the ocean beach, have been deprived of their ferruginous cuticles. The calcareous and glauconitic constituents of the red sandstone testify to the comparative tranquillity of the offshore conditions. The constant and well nigh interminable shifting of the sand on the beach causes any clay that may temporarily become entrapped to be washed out, while offshore the sand is slowly deposited grain by grain, with, as a rule, little subsequent disturbance, and the dead water due to the interstices and to surface friction makes the permanent entrapment of a certain proportion of clay inevitable. Hence the conclusions appear to be warranted that the ideal beach deposits, especially with a slow rate of subsidence, are white (free from clay and iron oxide), and that red sandstones, not composed of red feldspar, etcetera, may be due to the rapid deposition with little surf action of the clay coated or ferruginous quartz grains of the regolith, as suggested by Russell, or to the admixture of clay with sand which has been bleached by the surf during its slow deposition under offshore conditions.

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*Bull. 52, U. S. Geol. Survey, p. 44.

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LAKE IROQUOIS AND ITS PREDECESSORS AT TORONTO

BY ARTHUR P. COLEMAN

(*Read before the Society December 30, 1898*)

CONTENTS

IROQUOIS SHORE NEAR TORONTO

The recent finding of fresh water shells in Iroquois beach gravels close to Toronto appears to settle the long debated question as to whether the Iroquois water was a fresh water lake or an arm of the sea, and is perhaps of sufficient importance to justify a brief redescription of the whole series of lake deposits in the neighborhood. This must be the only excuse for adding to the already voluminous literature on the Iroquois beach and the complicated problems with which it is connected.

Although Dr Spencer long ago followed and determined the elevation of the Iroquois beach north of lake Ontario, as Dr Gilbert has done on the south, it seemed worth while to make a more careful survey of the old coastline in the neighborhood of Toronto, and the results of this are given in the accompanying map (figure 1), making it unnecessary to give details of the interesting topography revealed. After the survey had been made it was found that the western bay, reaching from Toronto Junction to Weston, had been roughly mapped and briefly described by Sandford Fleming in 1861.* It is worthy of note that the two sand and gravel spits closing the mouths of the Humber and Don bays of lake Iroquois were formed in very much the same way as the present Toronto island, the materials for which are now being transported from Scarboro

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* Canadian Journal, new series, vol. vi, 1861, p. 228.

hights on the east. Evidently the most effective wave action was prevalently toward the west in Iroquois times as now. The eastern bar, at the mouth of the Don bay, has a striking resemblance to the present Toronto island, including hollows which once were lagoons. The growth of these bars was followed or accompanied by the almost complete silting up of the two bays, which are now plains more or less dissected by the modern rivers, with their tributaries.

The shores of lake Iroquois near Toronto were usually low, with gently sloping swells of boulder-clay rising inland, but at two points, the Davenport ridge and Scarboro hights, they formed cliffs, in the latter case rising more than 150 feet above the water. At the highest part the Iroquois shore for half a mile lay to the south of the shore of Ontario, the only instance in its whole circumference where the old shore encroached on the territory of the present lake.

Figure 1.—*Map of Iroquois Beach near Toronto.*

As a result of the growth of the two bars shown on the map, the two main rivers were crowded toward the west, so that when the water fell to its present level the preglacial channels were not again occupied, but fresh ones were cut on the westward sides of the valleys. In the case of the Humber we find a wide valley, with little rock cutting above the old bar, and a narrow, steep walled channel cut through 50 feet or more of Hudson shale where the river passes the western end of the bar.

Fossils occur in the gravels of each of the bars described, the one at Toronto Junction affording numerous shed horns of caribou and wapiti at a depth of 12 to 20 feet below the crest of the ridge, while a mammoth's tooth has been obtained from the eastern bar, near the town of York.

Professor Hall stated many years ago that shells were said to have been found in beach ridges in the state of New York, though he himself had not seen them,* and there was a report more recently that marine shells were found in the Hunter Street tunnel in Hamilton, but they turned out to be Silurian brachiopods from drift boulders in the till. Until recently this was all the evidence on record as to the character of the Iroquois water.

The opening of a sand and gravel pit two years ago by the city authorities of Toronto, near the Reservoir park, disclosed a few fresh water shells, mostly in fragments. Last autumn the pit was opened more extensively, and numerous shells were picked up by the writer, by the workmen in the pit, and by students and others interested in geology. As many of them were taken directly out of the undisturbed gravel, there can be no doubt that the shells belong where they were found. They include many specimens of *Campeloma decisa*, in general well preserved; a number of pleuroceras, probably of more than one species; sphæriums, and badly worn portions of unios.

These fossils occur 150 or 160 feet above lake Ontario and nearly 100 feet above the Don valley deposits, a half mile away, from which so many shells have been obtained. The Don beds, beside lying so much lower, seldom contain campeloma, the commonest fossil at the Reservoir park gravel pit, so that these beds can not be confounded with the much earlier interglacial deposits.

The beds opened are evidently of Iroquois age. They are at the right level, are coarsely stratified, cross-bedded beach deposits, and lean against an escarpment of till about 25 feet high, a continuation of the Davenport ridge, the old shore cliff of the Iroquois beach. There are really two gravel pits, an upper one north of the Canadian Pacific railway and a lower one south of it. The shells are found only in the deeper layers not reached in the upper pit, though the two excavations are evidently in the same deposit.

Fossils from other raised Beaches

The conclusion that the Iroquois water was fresh is entirely what might have been expected, since other postglacial deposits of the Great Lake region have already been shown to contain fresh water shells. Warren Upham reports unios and sphæriums from lake Agassiz,† and

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* Geol. of New York, part iv, 1843, p. 349.

† Warren Upham: Glacial Lake Agassiz, U. S. Geol. Survey, vol. xxv, p. 237.

I have found the same two genera in the old lake deposits of Rainy river, said by Upham to have been formed in an arm of lake Agassiz, but by Tyrrell to belong to a later lake. Dr Bell has found fresh water shells in old lake deposits north of lake Superior, and lake Warren (or possibly lake Algonkin) left many species of fresh water shells in its muds and sands near Georgian bay. Professor Chapman, formerly of Toronto University, gives a list of 11 species from Angus, south of Georgian bay, and the present writer has collected 19 species from the same region.

These great sheets of water, then, from Agassiz to Iroquois, were evidently fresh. A fragment of marine shell picked up last summer in the Peninsula gravel pit north of lake Superior has been submitted to Dr Dall, of the Smithsonian Institution, who pronounces it that of a recent oyster, but as the transcontinental trains of the Canadian Pacific railway pass along one side of the ballast pit, there seems no doubt that the shell reached its position by human agency.

All the evidence, then, afforded by fossils speaks of fresh water, and it fails altogether to support the idea that the sea has invaded any part of the Great Lake region in Glacial or post-Glacial times. It is a striking fact, however, that marine deposits occur but a short distance away in the Saint Lawrence valley to the east, the Ottawa valley to the northeast, and on the shores of the rivers flowing into Hudson bay on the north. Sir William Dawson and others note the Leda clays and Saxicava sands, often with numerous subarctic marine shells, all along the Saint Lawrence valley up to 550, or perhaps 600, feet above sealevel. Similar shells and marine fish occur along the Ottawa, and the bones of a whale have been found 420 feet above sealevel in a railway gravel pit near Smiths Falls, between the two rivers.* Dr Bell and Mr Tyrrell report marine terraces with shells not more than 200 miles north of the Great lakes.

WARPING OF THE IROQUOIS BEACH

It is evident that if the sea rose uniformly over the eastern part of Canada and the adjoining states the lake Ontario basin, which now stands 247 feet above the sea, would be deeply submerged when marine terraces were being formed at Montreal, 550 feet above the present sealevel, so deeply as to rise 130 feet above the Iroquois beach at Toronto. However, the researches of Gilbert and Spencer prove a very marked differential elevation of the old beach, which is now tilted up at its northeastern end.

Spencer holds that if we subtract the total elevation of the land since Iroquois times it will leave the beach at the level of tidewater. To test

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* The Canadian Ice Age, 1893, p. 63; also pp. 195–203.

this view, my friend Dr Ellis has aided me in working out a curve to represent the differential elevation of the region. The hights of the beach above present sealevel were taken from Spencer's History of the Great Lakes and used as ordinates, while distances from Hamilton, at the west end of the lake, served as abscissæ. It was found, to our surprise, that the direction northeast did not bring the readings into anything like harmony, those south of lake Ontario being too low as compared with those to the north. After numerous trials the direction north 17 degrees east was observed to harmonize the elevations given by Spencer in the most satisfactory way, and the diagram resulting is reproduced here. It will be noticed that the determinations as a whole form an evident curve rising at a rapidly increasing ratio in the direction of north 17 degrees east. The irregularities may be accounted for probably by the fact that in some cases the hight of the crest of a bar was measured; in others that of the plain at the foot of a shore cliff. It should be added that Mr Gilbert finds several beach lines on the north side of the lake, near its eastern end, having quite a range of elevation, and thinks there are records of two intersecting water planes. As the records of his work have not reached me, they can not be made use of here, and the curve is given as

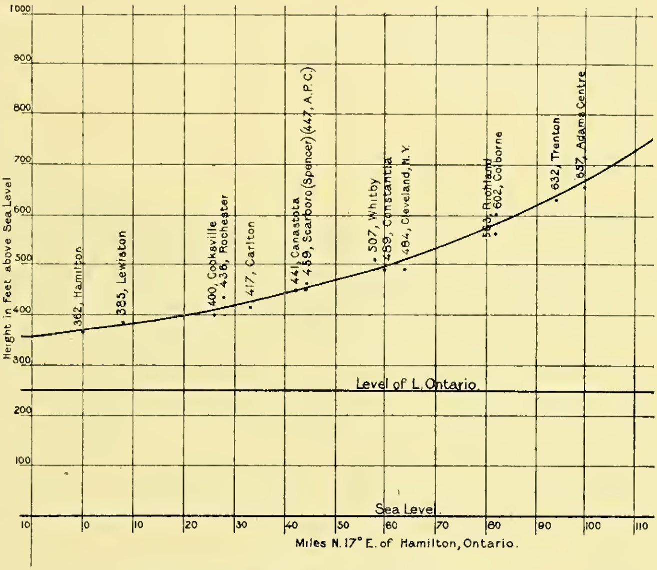

Figure 2.—*Curve of Elevation of Iroquois Beach.*

Projected on a vertical plane running N. 17° E.

worked out.* A glance at the diagram will show that the curve rapidly approaches a horizontal line as it advances southwest, and that horizontality would be reached much above sealevel. On the other hand, it is clear that the northeast projection of the curve would run far above the 600-foot beach at Montreal, or any elevation at which marine shells have been found, along the rivers flowing into Hudson bay. It can not be assumed, of course, that the curve of elevation would continue indefinitely toward north 17 degrees east. There must be somewhere a gentle anticline, beyond which there is a downward slope, unfortunately not recorded in the wide valleys of the Saint Lawrence and Ottawa.

The researches of Messrs Gilbert and Taylor seem to prove that after the Iroquois lake was drained there was a short time during which the gulf of Saint Lawrence extended into the Ontario basin,† and it may be that the whole of the marine beaches of eastern Canada are post-Glacial in age, and therefore later than the Iroquois beach.

INTERGLACIAL WATER-LEVELS

Thus far we have followed in brief outline the record of changes of water-level as disclosed in old beaches, and a most wonderful and complicated history, even yet only imperfectly understood, has been unrolled before us by Gilbert, Spencer, Taylor, and others. It must not be forgotten, however, that this tangle of beaches and deserted waterways represents only the latest series of episodes in the history of the Great lakes, the results of the removal of the last ice-sheet and of the later changes of level of eastern America. We may imagine that the slow advance of the great ice-sheet produced a similar series of lakes, but in ascending instead of descending order, beginning with a greater lake Ontario far earlier than the Iroquois lake, proceeding to a lake Algonkin, a lake Warren, and a lake Agassiz. Unfortunately this must all be left to the imagination, since no record of the first ice advance, in so far as it affected water-levels in the Great Lakes region, has been discovered up to the present. The same may be said of the earlier inter-Glacial period or periods. It is only when we come to the later inter-Glacial times, which have left their record in the Don and Scarboro sections, that we have certain evidence of changes of water-level, and this evidence refers to the Ontario basin only.

It may be that some will object to the assumption of an inter-Glacial

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* Since this paper was written copies of the Sixth Ann. Rep. of State Reservation at Niagara, 1890, and of "Recent Earth Movement in the Great Lakes Region" have been obtained, giving valuable information on this point. The isobasic curves on page 604 of the latter paper give a reason for our difficulties in reducing the levels to the curve shown in the diagram.

† F. B. Taylor: A short History of the Great Lakes, p. 20.

period, holding that the Ice age was a unit. It is not intended to discuss this question here at length, but merely to show what all who have studied the drift sections near Toronto will admit, that there was a great and long continued recession of the ice from the region of lake Ontario during the time of the Toronto formation, even if the ice-sheet was not completely thawed away.

The Toronto formation* gives no hint of changes connected with the withdrawal of the ice during the earlier part of the inter-Glacial period, but commences with a warm climate deposit resting on a bed of till. The numerous plants and animals found fossil in these beds show a climate distinctly warmer than the present at Toronto and incompatible with the presence of a huge mass of ice a short distance away. The cases of the Malaspina and other Alaskan glaciers ending close to a luxuriant vegetation, and of the Swiss glaciers whose foot reaches the level of orchards and vineyards, brought forward by Warren Upham to show the probable continuity of the Ice age during the deposit of the Toronto formation, do not furnish a parallel to the state of affairs in inter-Glacial times on lake Ontario, since in the latter case there were no lofty mountains to afford *nevé*, as in the instances referred to. We may conclude, then, that the Don beds of the Toronto formation indicate the middle of a mild period, with ice too far away to dam any valleys of the region.

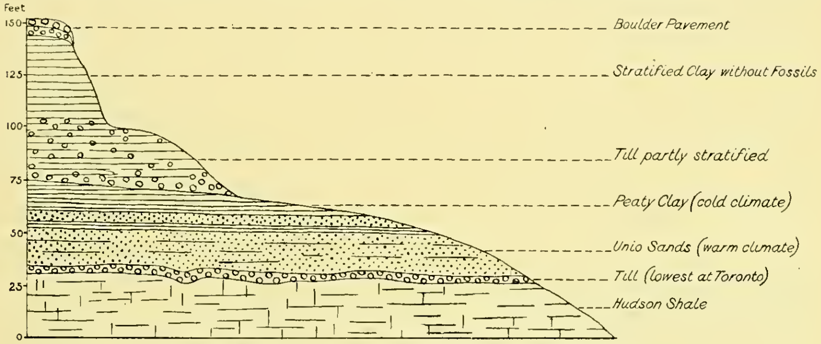

FIGURE 3.—*Section at Taylor's Brickyard, Don Valley.*

At this time Scarboro hights, now rising 350 feet above lake Ontario, did not exist. Instead there was a depression reaching more than 40 feet below the present lake level at that part of the region, and a greater lake than Ontario stretched a bay to the northward or northwestward to what distance is unknown. The water stood at least 40 feet, and prob-

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* See G. J. Hinde : Glacial and Interglacial Strata of Scarboro Hights, Jour. Can. Inst., vol. xv, p. 388; Interglacial Fossils from the Don Valley, Am. Geologist, vol. xiii, Feb., 1894, pp. 85–95; Glacial and Interglacial Deposits near Toronto, Jour. Geol., vol. iii, no. 6, 1895, pp. 622–645, and Report on Canadian Pleistocene, Committee of British Association, Bristol, 1898.

ably 50 or 60 feet, above the present lake, but not more, since at this level in the Don beds the warm climate fossils cease, and just below it a series of sand and gravel beds containing much brown oxide of iron hint at shallow water and oxidation. It may be added that the finding of unios in the position where they lived, just over the boulder clay, 35 feet above lake Ontario, suggests the same thing, as they are stated to live in shallow water only.

This lake, 50 or 60 feet deeper than the present Ontario, could not have been dammed by ice during the genial Don climate, but may have been held up by a drift deposit near its eastern end, though more probably supported by a more extensive differential uplift near the Thousand islands than the one which holds up lake Ontario at present.

Without any apparent discordance the warm climate beds are followed by a great thickness of buff stratified clay containing many thin peaty layers with extinct insects and plant remains of a comparatively cool but not arctic climate, as shown by Dr Scudder, Professor Penhallow, Dr Macoun, and others.* The latter may be called the Scarboro beds of the Toronto formation, since best shown at Scarboro hights. At this time, and probably during the preceding Don stage, a great river, the successor of Spencer's preglacial Laurentian river, drained the upper lakes, flowing from the Georgian bay to a point north of Toronto, where it formed an extensive delta deposit, now best displayed at Scarboro hights. The Scarboro peaty clays rise on the shore of lake Ontario, 95 feet above the

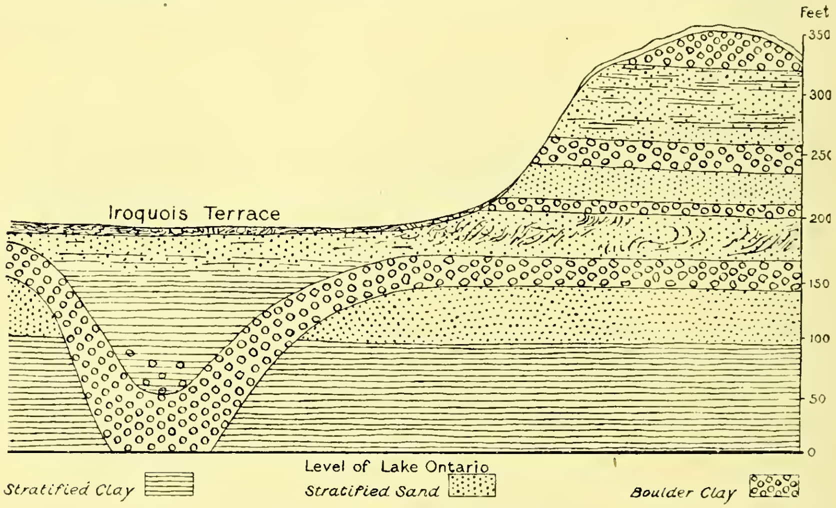

FIGURE 4.—*Section at Scarboro Hights.*

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* See papers previously quoted.

water, and extend 15 or 20 feet below the surface, as shown in wells sunk last year by the Pleistocene committee of the British Association for the Advancement of Science, at the foot of the hights. Inland these easily recognized peaty clays rise to 145 feet north of Reservoir park, and have been found near York mills, more than 6 miles north of Toronto bay. How much farther inland they extend is not known. While the peaty clay rises only 95 feet above the lake at Scarboro, a conformable series of stratified sands containing wood and a few fresh water shells rises 50 feet higher, so that the lake in the times of the Scarboro deposits stood at least 145 feet above the present water-level.

The cause of this deepening of the water from 60 feet or less to 145 feet or more above the present lake is not certain. The climate, as shown by the authorities quoted above, was about that of the north shore of lake Superior or the south shore of Labrador at present. It was not arctic nor even subarctic, but cold temperate. The clays and sands contain no boulders such as one would expect to find in a glacially dammed body of water with large ice masses drifting on its surface, but some beds of clay are crumpled in a way that might suggest the shove of an ice-floe. It seems most probable that the uplift which held back the Don waters increased during Scarboro times, ultimately reaching 145 feet or more at the east end of the basin. The great river which entered the Scarboro water at an unknown distance north of the present shore of Ontario, bringing down fragments of moss, wood, and bark and innumerable drowned beetles from the regions to the northwest, demanded a wide outlet to the sea somewhere toward the east, and probably followed the present valley of the Saint Lawrence.

Another point suggesting that this body of water in which the Scarboro delta deposits were laid down was not ice-dammed is the fact that before the next great glacial advance the Scarboro water was drained off to a level below that of lake Ontario. The proof of this is to be seen in the section of the Scarboro cliffs, where valleys as deep and wide as those of our present drainage system were carved in the delta deposits before the next till sheet was spread over the region.

If the reasoning here given be accepted, we must assume that the eastern end of the basin rose 145 or more feet above the western end, as compared with the present lake level, during inter-Glacial times, and then sank again to a point somewhat below the modern water plane before the ice advanced once more.

The series of changes just outlined might be accounted for by Warren Upham's theory that the land is lowered by the pressure of the mass of ice during a glacial advance and rises again when the load is removed.

It may be supposed that the interglacial relief from pressure allowed the northeast part of the continent to rise, thus damming back the waters of the Scarboro lake. Ultimately, however, the rise may have been sufficient to cause the formation of fresh snowfields and an ice-sheet, loading down Labrador and Quebec once more till the region sank under its burden and permitted the Scarboro basin to be drained again. If this theory is correct, the ice must have advanced southwest very slowly, for after the lowering of the northeast end of the lake sufficient time elapsed to allow the interglacial valleys to be cut down to a base even lower than the present one. It should be added, however, that the thickness of drift materials cut through was not much over half the average thickness of the beds in which the present Don river is carving its valley.

Water-levels during last Advance of the Ice

The cutting of the interglacial valleys no doubt required a long time, perhaps thousands of years, but at length the ice-front advanced far enough to fill the lower end of the Ontario valley, ponding back the water to a far higher level than we have any record of before, since stratified sands and clays are found at Scarboro and north of Toronto at least 320 feet above lake Ontario.

At the former point there are four well defined beds of till with stratified materials between, the whole series of deposits reaching a thickness of 200 feet. It is very probable that when these beds were formed the ice-front crossed the basin of lake Ontario diagonally just northeast of Toronto, sometimes advancing and at others retreating, the water rising high along its face. It would be of great interest to determine whether any equivalent series of high level, stratified and unstratified, glacial beds exists in the state of New York to the east or southeast of Scarboro.

It is probable that during this last invasion of the ice the region stood much lower than now, so that the stage of apparent high water was not actual but only relative to the present level. The land surface may even have been 570 feet lower than now, so that but for the intervening mass of ice it might have been flooded by the sea. No fossils have yet been found in these beds at Scarboro to determine the character of the water, but in an interglacial bed of stratified sand three and a half miles north of Toronto bay, overlying the till sheet which covers the Toronto formation, several species of fresh water shells occur 220 feet above lake Ontario. These sands rise 27 feet higher and have a thin bed of till interstratified with them near the top. It is probable that this deposit is equivalent in age to part of the interstratified sands between the upper layers of till at Scarboro, which would indicate fresh water in the lake of the time.

This body of water may have been much deeper than is indicated by the highest stratified materials observed near Toronto. It may even have been part of one of the great postglacial lakes whose beaches have been traced farther west, as, for example, lake Warren; but it is more probable that the high-level stratified sands and clays were formed before the ice had advanced to its farthest point, in a lake whose beaches were destroyed as the glacier pushed toward the southwest, and so can not be connected with any body of water hitherto described. The highest stratified bed at Scarboro is covered by 30 feet of till, forming the edge of the gently rolling morainic sheet of the country to the north. This brings to an end the succession of interglacial lakes, as shown near Toronto.

The final retreat of the ice formed lake Warren, of which there are no certain evidences, however, in this region, and at length lake Iroquois, probably the last of the splendid series.

Conclusions

Reviewing the old water-levels of the Ontario basin, as sketched in the foregoing paper, we find that the records commence with the Toronto formation at the middle of an inter-Glacial period, and that the succession may be represented in the following table:

a. Interglacial Lakes

1. Don stage, warm climate, fresh water shells, dammed by differential elevation toward northeast to about 60 feet above present lake. Successor to Laurentian river enters north of Toronto.
2. Scarboro stage, cold temperate climate, fresh water shells, deposits conformable with those of last level, but reach 145 feet, and consist of delta materials of Laurentian river.
3. Low water stage with subaerial erosion and cutting of river valleys to a depth below present lake level.
4. High water stage, glacial or subglacial climate, probably fresh water shells, ice dammed to a hight of at least 320 feet.

b. Bodies of Water Accompanying Retreat of Ice

5. Probably lake Warren, subglacial or cold temperate climate, fresh water shells (near Georgian bay), ice dam.
6. Lake Iroquois, temperate climate, fresh water shells, caribou, wapiti, elephants, 170 feet above lake Ontario, ice dammed.
7. Extension of gulf of Saint Lawrence over portions of Ontario basin.

The series of former water-levels in the Ontario basin as given above must, of course, be looked on merely as relative to the present surface of lake Ontario. What absolute hights they had above the sea one can hardly guess in the case of the first four, and even as regards lakes Warren and Iroquois the elevation above sealevel must for the present remain very doubtful.

It has seemed unwise to give separate names to the old lakes whose deposits lie, as one might say, encapsuled within one another in the Ontario basin, and reference has been made only to the various stages clearly shown in the drift of the region. The Iroquois beach, so magnificently displayed and so thoroughly studied, deserves, of course, a distinctive name. Possibly the example set by Tyrrell in his account of the old beaches west of Hudson bay might be followed profitably, naming the ancient lakes Epi-ontario number 1, number 2, etcetera. This method seems most applicable, however, to instances where there are well-defined beaches. When the dam at the outlet rises steadily without distinct pauses, as seems to have occurred when the Don interglacial stage merged into the Scarboro interglacial stage near Toronto, it is clear that no sharp line should be drawn between the successive bodies of water.

The complicated bit of history outlined in this paper affords fresh proof of the delicate balance of affairs in the Great Lakes region during the last few tens of thousands or hundreds of thousands of years, and is suggestive of the kind of changes which it may undergo in the future. Is the rest of America and the world in a condition of unstable equilibrium like that of the region of the Great lakes; or are the Great lakes situated where they are because the region is subject to greater and more frequent changes of level and of attitude than others?

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AUGITE-SYENITE GNEISS NEAR LOON LAKE, NEW YORK

BY H. P. CUSHING

(Read before the Society December 30, 1898)

CONTENTS

INTRODUCTION

Field-work in a portion of the Adirondack region during the past two years has disclosed the rather widespread occurrence of rocks which resemble some phases of the anorthosites, and were classed with them until inspection of thin-sections showed their quite different nature. Similar rocks prove to be of frequent occurrence in the district, and to have an extent and importance not heretofore recognized. They also possess considerable intrinsic interest, so that some preliminary notice of them would seem to be justified in advance of a thorough investigation of their field relations. These rocks are widely and quite typically exposed in the vicinity of Loon lake, in Franklin county, New York, and many of the exposures are easily accessible; hence their selection for descriptive purposes. The rocks are referred to the augite-syenites.

Megascopic Character

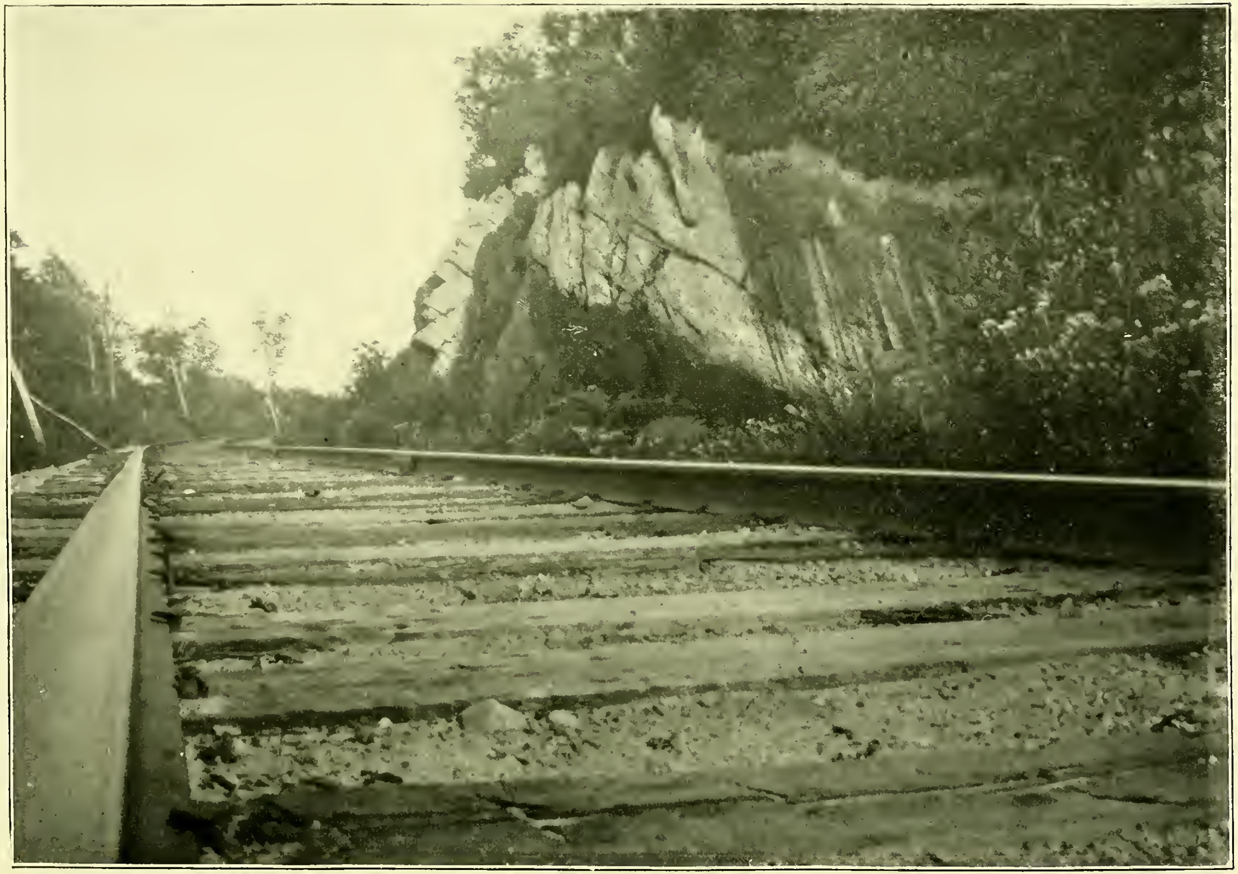
When fresh these rocks are of a grayish green color, which quickly changes to a more pronounced green on slight exposure. When longer exposed a further change to a yellowish or brownish green takes place, and then a passage into a rusty brown, which is the prevailing color of the exposures, except in recent cuts. The cause of these rapid color changes is not manifest, sections from specimens of the first three shades showing all the constituents to be perfectly fresh. Even the rusty brown rocks are often quite unaltered, though the hypersthene is commonly decomposed, suggesting staining from the oxidation of the ferrous oxide as a possible cause of the color here.

For the most part the rocks are of medium grain, though with much variation from place to place. They have been subjected to regional metamorphism in common with the other rocks of the district, and hence are rather evenly granular, though in most cases larger crystals are more or less abundant, suggesting cataclastic structure. Feldspar is much the most prominent mineral, constituting usually about 80 per cent of the rock. The uncrushed crystals are always less green than the granular feldspar. Pyroxene or hornblende and quartz make up the rest of the rock. Sometimes a little garnet and magnetite may be discerned. Biotite is locally present.

As a result of metamorphism, a rude foliation is commonly apparent, though with much variation from place to place, depending on the amount of ferromagnesian silicates present and on the degree of granulation. In other words, precisely the same range is shown that the gabbros exhibit, though very coarsely crystalline phases comparable to the coarse anorthosites have not been observed. In the more quartzose varieties the ferromagnesian silicates retreat with disappearance of the foliation, its place being taken by a rude linear structure due to the drawing out of the quartz into pencils.

Section near Loon Lake and its Interpretation

In the east end of Loon Lake mountain, south of and within 2 miles of the depot, the Adirondack and Saint Lawrence railroad has made three



RAILROAD CUT IN AUGITE-SYENITE, LOON LAKE, NEW YORK

The cut is half a mile south of Loon Lake depot. The dark portion is fresh and of green color; the lighter portion is somewhat weathered and is brown. Photographed by J F. Kemp August 2, 1898 rock cuts, which afford very interesting exposures.* In the first cut a fairly coarse augite-syenite is shown which has not been severely granulated, is practically non-foliated, and has a very evident cataclastic structure (plate 19).† The second cut shows quite similar material, though more crushed and with a better foliation. The third cut is quite extensive, and a generalized section of the exposures is given in the accompanying figure.

The augite-syenite constitutes the center and south end of the section. It is more thoroughly granulated and more gneissoid than in the preceding exposures. Separating the two syenite areas is a thickness of 12 feet of well banded gneisses. Above is a layer 2 feet thick of a white, granular rock composed of quartz and white pyroxene in the proportion of 1 to 2. This is followed by layers of granular, black pyroxene granulite and light colored quartzose rocks, the latter consisting essentially of quartz and potash feldspars, the quartz forming from 60 to 70 per cent of the rock. The structure and composition indicate a sedimentary origin for these included bands, and they are precisely like rocks which invariably accompany the crystalline limestones of the region, the white pyroxene being especially characteristic. At the lower contact with the syenite is a probable shear-plane, along which biotite is abundantly developed. This syenite is succeeded to the north by finely granular, red, granitic gneisses of doubtful origin, but also very similar to rocks which are of common occurrence associated with the limestones. The foliation planes of the syenite have the same dip and strike as the included gneisses.

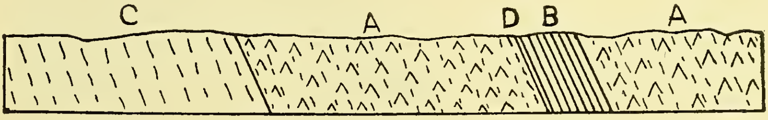


Figure 1.—*Section in Railroad Cut near Loon Lake, New York.*

A, augite-syenite. *B*, well banded quartzose gneisses. *C*, quartzose gneisses. *D*, biotitic sheared strip—strike north 10 degrees west. Dip of bedding and foliation 65 degrees to the west.

There can be no question of the sedimentary origin of the gneisses included under "B" in the section (see plate 20). With that as a starting point, the uniform dip and strike in the exposure, together with the finely granular character of the syenite, give the impression that the whole forms a regularly bedded series; but when the syenite is compared with the rock in the other cuts it is seen to be unquestionably the

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*These exposures were visited in company with Professor A. C. Gill in July, 1897, and with Professor J. F. Kemp in August, 1898, neither of whom objected to the interpretation here given.

†A photograph of this exposure is reproduced in plate 19 to indicate the color change due to weathering,

same, and that appears like a somewhat crushed intrusive rock. When it is recalled that the whole region has suffered profound dynamic metamorphism, producing a common foliation in the rocks irrespective of their origin; when it is further borne in mind that in the eastern half of the Adirondacks the rocks of the Grenville (crystalline limestone) series seldom occur in considerable belts, but rather in mere patches, and these patches are often wholly surrounded by undoubted igneous rocks, being found not infrequently inclosed in the anorthosites, and, further, that in the majority, if not in all cases, the bedding of the one and the foliation of the other are parallel, the seeming difficulty in the interpretation disappears; when, finally, the chemical nature of the rock is taken into consideration the case for its igneous origin seems made out.

It is not certain from the section whether the clastic rocks are in place and cut by large dikes of the intrusive, or whether they represent fragments caught up by the molten flood. Many examples of the latter might be cited from the eastern Adirondacks, and the great extent of the syenite in the vicinity of Loon lake with the scarcity of the Grenville series makes it the probable explanation here. Professor Kemp concurs in the view that these patches represent the remains of a once extended formation completely broken up by the great intrusions.

Microscopic Character and Mineral Constituents

The thin-section from the hand specimen chosen as typical and used for the chemical analysis shows the presence of the following minerals: Zircon, apatite, magnetite, garnet, hypersthene, augite, hornblende, oligoclase, microperthite, and quartz. Other slides from the vicinity of Loon lake show in addition biotite, titanite, allanite, and pyrite. The rock is essentially composed of microperthite, augite, and hypersthene, with quartz always present in varying and commonly slight amount.

Zircon and apatite are very sparingly present, are the only constituents with idiomorphic boundaries, and occur in the usual microscopic crystals as the earliest crystallization from the magma.

Magnetite is only in slight amount in irregular grains.

Allanite and titanite are found in only one of the slides and in only minute quantity. The titanite is of deep orange-brown color, like that in the pyroxene-granulites found associated with the magnetites of the Adirondacks. But two small fragments of allanite occur, so that its diagnosis is perhaps not beyond question, though the optical properties agree wholly with those of that mineral.

BANDED GNEISS INCLUDED IN AUGITE-SYENITE

The hammer is at the contact. Photographed by J. F. Kemp August 2, 1898

Garnet occurs only sporadically and is not idiomorphic, but appears in reaction-rim fashion between the magnetite and feldspar, sending out tongues into the latter mineral.

Of the pyroxenes, both hypersthene and augite are present, the latter usually predominating. Parallel growths of the two frequently occur, often of repeated fine lamellæ, the contact faces being as usual. Other growths appear also, and sometimes one mineral is found wholly included in the other, each appearing in that condition. Their boundaries are never idiomorphic, but always irregular and more or less rounded.

The hypersthene is quite typical, except that the prismatic cleavage is more pronounced than the pinacoidal. The augite recalls diallage in some respects, but the pinacoidal cleavage is absent or but poorly developed. The color is green, with a very slight pleochroism in the thicker slides, 𝔟 having a yellowish tinge. The ordinary color is very similar to the green of the hypersthene. Besides the prismatic cleavages there is a well developed parting parallel to the base. The extinction angle is between 45 and 50 degrees.

In the rock immediately under discussion hornblende is found in very slight quantity, though elsewhere present in considerable amount. Like the pyroxene, it appears in irregular grains, though sometimes there is an approximation to idiomorphic outlines. The absorption and pleochroism are very strong, 𝔞 being pale yellowish, 𝔟 deep brown, and 𝔠 dark green, with $\mathfrak{b} \geq \mathfrak{c} > \mathfrak{a}$. The 𝔟 color is very like the brown of the biotite, which also occurs sparsely in the more hornblendic rocks.

The feldspar is almost wholly microperthite. A few grains of plagioclase always appear and invariably extinguish nearly parallel to the trace of the albite twinning lamellæ. The greatest departure from parallelism in any of the slides was 7 degrees. In no other case does it reach 4 degrees. These fragments must therefore be referred to oligoclase. The chemical analysis shows that the plagioclase present must, as a whole, be considerably more acid than normal oligoclase and nearer to albite.

The feldspars are very fresh. They contain a small amount of cloudy, dust-like inclusions, and also include the zircon, apatite, titanite, and small augites, these latter being exceptional and idiomorphic. They also include small, idiomorphic or else rounded quartzes, as determined by Becke's method.

Orthoclase is only present as a constituent of the microperthite. There is no indication of zonal structure—that is, microperthite with oligoclase cores—as in the similar rock described by Smyth from Diana.*

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*C. H. Smyth, Jr.: This Bull., vol. 6, pp. 271–274.

Quartz occurs only sparingly in this rock, though very quartzose phases appear elsewhere in the Loon Lake vicinity. It is mainly in rather large, elongated, cylindrical individuals. The elongation seems to be effected rather by solution and recrystallization than by crushing. The individuals are either entire or made up of but few fragments, and the fine granulation which must have been produced by the crushing process is nowhere in evidence. In the quartzose varieties the ferromagnesian silicates recede with disappearance of the foliation, its place being taken by a linear structure produced by the elongated quartzes.

Some quartz is also found as inclusions in the feldspar, sometimes rather numerously and with a tendency to micrographic growths. There is also a small amount of interstitial quartz and orthoclase, which seems secondary.

Structure of the Rocks

These rocks have a cataclastic structure. In the gneissoid rock, from the third cut the granulation is pretty complete, but even there occasional larger nuclei remain and show undulatory extinction. In the coarser rock, from the first cut many such large fragments are found, constituting more than half the rock. The Diana rock shows the structure even better. Precisely the same variations in degree of granulation are to be found that the anorthosites exhibit, except for the lack of the very coarse varieties in the syenite, such as make up a considerable part of the anorthosite, but this is regarded as an original difference. In addition to the cataclastic structure, the rock is nearly everywhere foliated.

Chemical Analyses

TABLE OF ANALYSES

These syenites are so variable in mineral content and their field relations to other rocks, which on the one hand are much more acid and on the other more basic, and into which they apparently grade, are yet so uncertain that a large amount of chemical work will be necessary in order to fully elucidate the problems suggested. Only a beginning has been made in this, which, however, suffices to show the character of the typical rock and to permit of a certain amount of discussion and comparison with other syenites.

	I.	II.	III.	IV.	V.	VI.	VII.
SiO_2	63.45	65.65	65.43	66.60	66.13	59.78	64.35
TiO_2	0.07	....	0.50	0.76	0.74	....	......
Al_2O_3	18.31	16.84	16.11	15.05	17.40	16.36	15.46
Fe_2O_3	0.42	4.01	1.15	1.07	2.19	3.08	7.50
FeO	3.56		2.85	4.42		3.72	
MnO	None.	....	0.23	Trace.	0.13	....	......
CaO	2.93	2.47	1.49	2.21	0.81	2.96	3.58
BaO	0.13	....	0.03	....	....	....	......
MgO	0.35	0.13	0.40	0.36	0.04	0.69	0.50
K_2O	5.15	5.04	5.97	5.42	5.60	5.01	3.45
Na_2O	5.06	5.27	5.00	4.03	5.28	5.39	3.28
P_2O_5	Trace.	....	0.13	....	....	CO_2 0.75	......
Loss	0.30	0.30	0.78*	0.41	1.22	1.58	1.63
	99.73	99.71	100.18	100.33	99.54	99.96	99.84

Specific gravity of number I is 2.717 at 20° centigrade.

I. Augite-syenite (akerite), Loon lake, New York. Analysis by E. W. Morley.[†]

II. Augite-syenite (akerite) from Diana, New York. Description and analysis by C. H. Smyth, Jr., in this Bulletin, vol. vi, pp. 271–274.

III. Syenite, mount Ascutney, Vermont. Petrographical data by R. A. Daly, analysis by L. G. Eakins, in U. S. Geological Survey Bulletin no. 148, p. 68.

IV. Akerite, Gloucester, Massachusetts. Description and analysis by H. S. Washington, in Journal of Geology, vol. vi, p. 798.

V. Akerite, between Thinghoud and Fjelebua, Norway. Analysis by Mauzelius, description by Brögger, in Zeitschrift für Krystallographie, vol. xvi, p. 46, 1890.

VI. Syenite, Silver Cliff, Colorado. Description by Whitman Cross, analysis by L. G. Eakins, in 17th Annual Report, U. S. Geological Survey, part ii, p. 281.

VII. Banatite, Farsund, Norway. Description and analysis by Carl Fred. Kolderup, Bergens Museums Aarbog, 1896, p. 213.

DISCUSSION

The Loon Lake rock (column I) is composed of microperthite, augite, hypersthene, and quartz, with a little magnetite and oligoclase, and such small amounts of apatite and zircon that they in no way affect the totals. With this comparatively simple make-up it would seem an easy matter to calculate the composition of the rock. It soon appears, however, that the augite must be peculiar, and that a wholly satisfactory calculation can not be made until it has been analyzed. It must be either very rich in iron or alumina, or both, or else contain considerable alkali, but its optical characters are not those of any known alkaline pyroxene. Further, the available analyses of aluminous augites show that a high alumina percentage usually implies a large content of ferric iron, which is mani-

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[*] Includes F, 0.08; Cl, 0.05; FeS_2, 0.07.

[†] The great obligations of the writer to Professor Morley for this analysis are gratefully acknowledged.

festly impossible here. The only way of interpreting the analysis that suggests itself to the writer is to assume that the augite is essentially a lime, ferrous-iron, alumina silicate, unusually high in the last named oxide.

Calculation of Analysis I

1894

	Molecular ratio.	Magnetite.	Orthoclase.	Albite.	Anorthite.	Hypersthene.	Augite.	Quartz.
SiO_2	10575	....	3282	4896	318	174	745	1160
TiO_2	9	9	....	....	....	....	....	....
Al_2O_3	1795	....	547	816	159	....	372	....
Fe_2O_3	26	26	....	....	.....	....	....	... ...
FeO	494	35	....	....	......	87	372	....
BaO	8	....	....	....	8	....	... .	....
CaO	523	....	......	......	151	....	372	....
MgO	87	....	....	....	....	87	....	... .
K_2O	547	....	547	... .	......	... .	....	....
Na_2O	816	....	....	816	... . .	....	....	.. ....
Per cent	....	0.73	30.39	42.70	4.51	2.02	12.02	7.07

This result agrees quite well with that obtained by separation with heavy solutions, and can not be far from the actual composition of the rock. As it stands, the plagioclase is albite, $Ab_{19}\ An_2$, and the microperthite is approximately $Or_3\ Ab_5$. The plagioclase is in all probability not quite so acid as this would imply, as the augite undoubtedly contains a little soda, which would displace some of the lime calculated in that mineral, and both lower the albite and raise the anorthite percentage. It is thought that this change is only slight, not materially affecting the calculation.

The agreement between analyses I and II is exceedingly close. The Diana rock is even more feldspathic than that from Loon lake, which accounts for the increased silica and diminished lime and magnesia of the former; but the rock at Loon lake is quite variable, and specimens could be selected which would tally almost exactly with the Diana analysis. No doubt also the converse is true.

Of the other available published analyses of American syenites, the two which stand nearest the Adirondack rock are quoted in columns III and IV of the table. Of the Mount Ascutney syenite, no published petrographic description is available.* A hand specimen and slide in the writer's possession show a green feldspathic rock very similar to that

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* Dr Daly participated in the discussion following the reading of the paper before the Society, stating that the relations of the rocks of mount Ascutney had been carefully worked out and were in preparation for publication, and emphasizing the similarity of the Loon Lake rock.

from Loon lake except for its freedom from metamorphism. Hypersthene is lacking, and there is rather a predominance of hornblende over augite, which latter is colorless instead of green. Chemically it is closer to the rock from Diana than to that from Loon lake, but is lower in lime and magnesia than either. The agreement is, however, very close.

Likewise the syenite from Essex county, Massachusetts, just described anew by Mr. H. S. Washington, shows great similarity with the preceding.* It lacks hypersthene, and the augite is like that in the Mount Ascutney rock. The specimen analyzed is more acid than the Adirondack rock, with lower alumina, higher iron, and slightly lower alkalies, with the potash somewhat in excess of the soda. These differences are all slight, and of the essential identity of the rocks there can be no question. As stated by Washington for the Massachusetts rock, all belong to the variety of augite-syenite called "akerite" by Brögger and the "akerite type" by Rosenbusch—in other words, are quartzose augite-syenites. The analysis quoted by Washington of an akerite from Norway (column V) is appended, though, as stated by him, it is an acid representative of the group. Furthermore, it is unusually low in lime, much more so even than the Mount Ascutney rock. The analyses bring out clearly the considerable variation to which these rocks are subject. Not improbably they could all be duplicated in each locality.

All the rocks represented in the first five analyses are quartz-syenites and quite acid representatives of the syenite group, approaching the acidity of granites. Column VI gives an analysis of a more normal syenite, introduced merely to emphasize the departure of the others from the ordinary type.

Banatite is the name given by Brögger to rocks of the monzonite group (orthoclase-plagioclase rocks) which range between 62 and 67 per cent of silica. The analysis (column VII) will indicate the differences between them and these akerite-syenites, namely, the higher amount of lime and magnesia and lower alkalies. Rocks of the monzonite group are widely exposed in western Norway, a petrographical province which has many features in common with the Adirondacks, in close association with rocks of the gabbro group, anorthosites, norites, and so on. They have recently been exhaustively investigated by Kolderup,† and will be reverted to later.

GEOLOGIC AGE

Quite fortunately the exposures in the railroad cuts near Loon lake furnish data for a rough determination of the age of the syenite. For

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[*] Jour. Geology, vol. vi, pp. 796–798.

[†] Bergens Museums Aarbog, 1896, no. V.

a long period before the deposition of the Potsdam sandstone the Adirondack region was above sealevel, so that none but igneous rocks are found representing the time interval between the Potsdam and the only older sedimentary formation known in the district, the crystalline limestones and associated quartzites and gneisses. These latter are evidently the equivalents of the Grenville series of Canada. The syenites are younger than the Grenville rocks, for they cut or include them, as already noted. On the other hand, they are older than the youngest of the pre-Potsdam rocks, the diabases, for they are cut by them. In the first cut, 100 rods south of the depot at Loon lake, the syenite is traversed by a diabase dike 3 feet wide.

These diabases have not been metamorphosed, whereas the syenites have suffered change of such a character as to indicate that during the process they were deeply enough buried beneath deposits since eroded away to be in the zone of flow, so that a long time interval must lie between the two. In addition to these syenites, the gabbro rocks and certain granites are later than the Grenville rocks and much older than the diabases. The relationships of the gabbros, syenites, and granites to one another will be reverted to later. It should be stated that they are older than the Essex county, Massachusetts, rocks, which cut Lower Cambrian strata, according to Sears,* and are likely older than the Mount Ascutney syenite as well.

ADIRONDACK SYENITE AREAS

LOON LAKE

The Loon Lake syenite belt is quite extensive, having a length of nearly 20 miles and a breadth of 10, though of irregular shape. These figures are advanced with some hesitation on account of the difficulty of recognizing the rock in ordinary exposures, especially toward the periphery of the belt. It is only in recent cuts that fresh material is to be obtained. In ordinary outcrops a rusty, brown gneiss prevails, which may or may not show greenish, less weathered nodules when broken. The much elongated character of the quartz-augen often shows characteristically in these weathered rocks, and considerable dependence has been placed upon it as a criterion for their recognition; but this is only of avail in the more acid phases, whereas the fresh rocks are found to pass into varieties in which the ferromagnesian silicates become more prominent and quartz recedes. Weathered rocks of this type have a wide range. They are finer grained and better foliated than the type and,

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*J. H. Sears: Bulletin Essex Institute, vol. XXII, 1890.

when weathered, are absolutely not to be distinguished from other rocks of apparently quite different relationships.

A variation is also shown in the opposite direction. Belts of very acid, red granitic gneisses consisting essentially of microperthite and quartz, with or without hornblende and augite, occur in the syenite-gneisses and *seem* to grade into them. For the most part they differ greatly in appearance from the usual granitic gneisses of the Adirondacks, being of coarse grain, with the quartz in the much elongated form in which it is found in the syenite-gneiss. These rocks are not so well shown in the Loon Lake belt as in others to be mentioned. The *seeming* gradation of the one into the other, the identity of the hornblende and augite, when they occur, in the two rocks, and the peculiar type of quartz are the reasons for assuming a near relationship to one another.

SALMON RIVER

A smaller belt of syenite-gneiss, some 6 miles long and 2 miles broad, runs from a point about 7 miles south of Malone down into Duane township. It is cut through by the Salmon river and the rocks well exposed, especially at Chasm falls. The fresh green gneisses are quite like those at Loon lake; but red gneisses make up a more considerable part of the exposures here, and in part the color is produced by weathering, instead of indicating a more acid rock. As a whole, hornblende is more prominent and pyroxenes less so in this belt, but no other differences appear and the identity of the rocks is beyond question. The only doubt is in regard to their areal extent, as they fade out into other rocks through puzzling intermediate phases.

DIANA

According to Smyth the Diana syenite belt is from 15 to 20 miles long and 2 to 4 broad, with very indefinite limits on all sides but the north.* To the south patches of it appear frequently in the midst of gneiss, into which it seems to blend, although the relation is obscure. Irruptive contacts with the limestones of the Grenville series are well shown, especially at Bonaparte lake. Professor Smyth writes me that he has found no other large area of this rock in the western and southern Adirondacks, though occasional small patches occur, with a wide range in distribution.†

MOUNT DEFIANCE

Professor Kemp has called my attention to the probable identity of

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*C. H. Smyth, Jr.: This Bull., vol. vi, pp. 271–'74.

†An extended description of the Diana belt will be found in Professor Smyth's forthcoming report in the 17th Ann. Rep, State Geologist of New York.

the rock which constitutes mount Defiance, near Fort Ticonderoga, with these syenites, and inspection of his specimens and slides fully confirms the suggestion. Here also hornblende is more prominent than at Loon lake, but the characteristic augite is also conspicuous. Allanite occurs here likewise.*

BIG TUPPER LAKE

Rocks which are at least in part to be classed with these augite-syenites are excellently exposed along the shores of Big Tupper lake and extend widely to the north and east. They are closely involved with red granitic gneisses which equal them in extent and into which they grade. Together with these are other granites, of whose relations nothing can be said, as no contacts have been seen.

RELATIONSHIP TO THE ANORTHOSITES

The main interest attaching to the Tupper Lake syenite lies in the evidence it may be expected to furnish concerning the relations of the syenites to the anorthosites. A large area of anorthosite in southern Franklin county, in the heart of which the Saranac lakes lie, is surrounded by the Tupper Lake syenite on the south and west.

It may be said, in the first place, that the syenite cannot differ greatly in age from the anorthosite, having been intruded into the Grenville rocks and subsequently metamorphosed under the same conditions as to load, as shown by the character of the metamorphism. Again, their areal distribution indicates consanguinity. Further, the identity of many of the minerals in them and in the granitic gneisses as well combines to render it strongly probable that all have resulted from a common magma.

With such ideas in mind, a series of traverses were attempted from one to the other, which were unsatisfactory, owing to a lack of outcrops at the more crucial points. In some cases a blending of one rock into the other seems apparent in the field. The anorthosite becomes much crushed and very gneissoid near the peripheral parts of the mass, the blue labradorite-augen showing constant decrease in number and eventually disappearing entirely. When fresh these crushed rocks are much like the syenite in color and appearance, and weather into brown gneisses the exact counterparts of the weathered syenites, so that it is impossible to tell when the passage from one rock to the other is made, but the thin-sections do not wholly bear out the idea of such a blending. Anorthosites are found which contain both orthoclase and quartz, denoting an

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* J. F. Kemp: Rep. State Geol. N. Y. 1893, pt. i, p. 452.

approach toward the syenite, but no strictly intermediate varieties are yet forthcoming.

In other places the passage from one rock to the other is quite abrupt, with no sign of blending. Unfortunately no contacts have been noted, so that there is nothing to show which rock is the older. In two or three instances what seem to be small inclosures of unmistakable anorthosite in the syenite have been noted, but in each the latter is far from fresh, and there is some question of its identity.

The fact that areas of each are found wholly apart from any trace of the other is good evidence for the separate nature of the intrusions; nor is there any reason why differentiation should not have taken place for the most part before the intrusion of either, and yet that a further differentiation of local character should not also take place in parts of the anorthosite after reaching their present resting place and while yet uncooled.

SIMILAR PETROGRAPHIC PROVINCES

CANADA NORTH OF MONTREAL

The rocks of the Adirondacks are most naturally compared with those of Canada to the north, being separated from them by a comparatively narrow belt of Paleozoic rocks, beneath which the two are undoubtedly continuous. That rocks corresponding to these syenite-gneisses are present there is undoubted, though as yet no attempt has been made to differentiate them from the other gneisses of the region. This is not surprising, considering the difficulty of the task and the nature of the country to be explored.

Adams has described the Saint Jerome anorthosite as

> "Surrounded by a zone of rocks of varied character, many of which strongly resemble the anorthosite in appearance, but are quite different in composition," and which "consists chiefly of rocks which, in addition to augite and plagioclase, contain variable amounts of hornblende, orthoclase, and quartz, and which are thus intermediate in character between the gneiss and the anorthosite, some of the many varieties represented approaching more nearly to gneiss and others more nearly to anorthosite in character and composition."*

He expresses the opinion also that the zone is to be regarded as a peculiar border facies of the anorthosite. If this be the true explanation and the writer is correct in his correlation, the area furnishes evidence of the passage of one rock into the other of much more decisive character than any yet forthcoming in the Adirondacks.

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*F. D. Adams: Geol. Surv. Can., Ann. Rep., vol. viii, 1896, pt. J, p. 121.

In the same report a number of pyroxenic gneisses are described as of doubtful origin, and some of them may belong here, though the majority of them are clearly referable to Adirondack types, which have nothing to do with the rocks under discussion.*

There are further described from many localities granitic gneisses with elongated quartzes, "leaf gneisses," which seem in part identical with those which appear in the Adirondacks associated with the syenite gneisses as apparent extreme phases of the magmatic differentiation.

LAKE SUPERIOR

Though the geological record preserved in the rocks of the Upper Lake region is a much more complicated and complete one than that to be read in the Adirondacks, still there is a close parallelism in the eruptive rocks of the two districts, as has frequently been urged by N. H. Winchell. Similar syenitic rocks also occur there with the same close relationship to the gabbros, so far as can be told from the descriptions, and have been described by Wadsworth and others.

NORWAY

Kolderup has recently described exhaustively a most interesting series of rocks which occur in the vicinity of Ekersund and Soggendal, in western Norway.† Unlike the other two Norwegian anorthosite areas, this one has not suffered regional metamorphism, so that the field relations are exceptionally clear. He shows that the original magma of the district has produced by differentiation anorthosite, norite and quartz-norite, and the various members of the monzonite group (orthoclase-plagioclase rocks), monzonite, banatite, adamellite, and granite. The order of appearance, according to Kolderup, was first anorthosite, then norite and monzonite, later adamellite and granite, and finally banatite, with no considerable interval of time between any but the first and second. Last of all and considerably later are dikes of diabase and augite granite. All these rocks agree closely in their mineralogy with the Adirondack eruptives.

SEQUENCE OF ERUPTIONS IN THE ADIRONDACKS

It is yet too early to attempt any complete discussion of the Adirondack igneous rocks, and, owing to the excessive regional metamorphism, it is an exceedingly difficult problem to work out the details of their

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* Ibid., pp. 67–82.

† Carl Fred. Kolderup: Das Labradorfels Gebiet bei Ekersund und Soggendal, Bergens Museums Aarbog, 1896.

history, but the similarity with the Norwegian rocks just mentioned is so great that it demands notice. The anorthosites are common to both regions. The norites and quartz-norites are also represented in the Adirondacks, partly as peripheral phases of the anorthosites which were undoubtedly produced by differentiation in place, and partly as somewhat later eruptions which cut the anorthosites and also the older gneisses, but which have not been noted cutting the syenite-gneisses. These norites grade into very basic ilmenite-norites and into quite pure masses of ilmenite in both regions.

The rocks of the monzonite group are represented in the Adirondacks by the syenitic and granitic gneisses here discussed. These rocks have certainly a range in silica percentage sufficient to include the banatites, adamellites and granites of Ekersund-Soggendal, and as far as can be judged from thin-sections the more basic monzonite end of the series is represented as well. In these rocks we meet the first considerable difference in the two districts. The Adirondack rocks, so far as chemically studied, run too low in iron, magnesia and lime, and too high in alkalies to be classed in the monzonite group (see analysis VII of the table), though the corresponding mineralogic difference is mainly to be seen in the character of the plagioclase, which is oligoclase in the latter and albite in the former. This likely points to some slight difference in the composition of the original magma, but the general resemblance is so close as to be very striking. Finally, in both regions the eruptive activity closed at a later period with the formation of diabase dikes accompanied by more acid rocks, syenite-porphyry in the Adirondacks and augite-granite in Norway.

A word of comparison with the Essex county, Massachusetts, petrographical province may not be amiss. The igneous rocks of the latter, according to Sears, consist of granites, syenites, and quartz-syenites, nepheline-syenites, essexites, diorites, and gabbros, all of which are cut by numerous dikes.* Leaving out the nepheline rocks, these are the same types as occur in the Adirondacks; but when the relative preponderance of the different varieties in the two provinces is taken into consideration it is clear that the original magma in the Adirondack region must have been considerably the more basic of the two, being lower in silica and the alkalies and higher in lime and magnesia; hence the prominence of gabbros in the one and of alkaline syenites in the other. Notwithstanding this considerable difference, some almost identical rock types appear in each as a result of differentiation. It is of interest to note that the two areas present almost precisely the same

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* J. H. Sears in Bulletin Essex Institute, vol. xxvii, 1895.

contrast to one another that is exhibited by the Christiana and Ekersund-Soggendal districts of Norway.*

SUMMARY

1. A quartz-augite syenite gneiss near Loon lake is described as regards its field relations and megascopic and microscopic characters.

2. Chemical analysis shows it to be a member of the syenite group and an acid representative of the variety called akerite by Brögger.

3. It is shown to be nearly related to the anorthosites in age, inasmuch as it is intrusive in the Grenville series, but much older than the pre-Potsdam diabases of the region.

4. Other Adirondack localities are briefly described, and the rock is shown to vary within quite wide limits, ranging from a granite to syenites more basic than the one analyzed.

5. The relations of the syenites to the anorthosites are discussed, showing a lack of decisive evidence, but indicating that syenites are in part a result of differentiation in the anorthosite magma after reaching its place of final cooling and in part are somewhat later in date.

6. Comparison is made with the similar petrographic provinces of Canada north of Montreal and of Ekersund, Norway, followed by a discussion of the order of eruption of the Adirondack eruptives, which is anorthosites, norites and diabasic norites, syenites, and granites, followed later by diabases and syenite porphyries.

7. A brief comparison with the Essex county, Massachusetts, province suggests that the original magmas in the two districts were quite different, yet another instance is added by them to the many already known of very similar rocks produced by the differentiation of quite dissimilar magmas.

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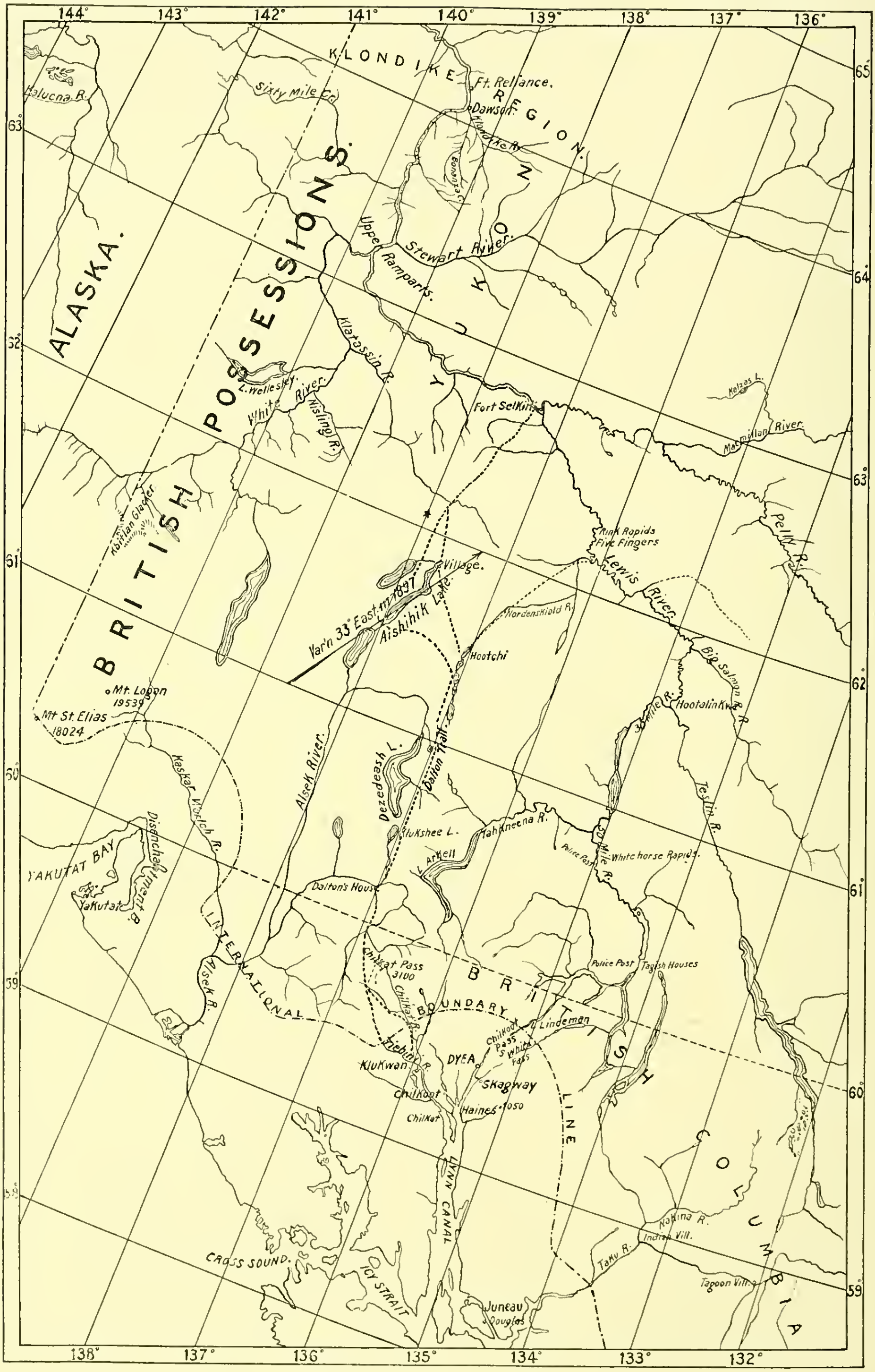
*See Kolderup, loc. cit., pp. 191-194.



CANADIAN YUKON DISTRICT

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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GLACIAL PHENOMENA IN THE CANADIAN YUKON DISTRICT

BY J. B. TYRRELL

(*Read before the Society December 29, 1898*)

CONTENTS

INTRODUCTION

Last summer, while traveling on horseback and on foot through the southwestern portion of the Yukon district and the extreme northwestern parts of British Columbia, many opportunities presented themselves for observing glacial phenomena—opportunities such as would hardly occur to those who were passing through the same country in boats on some of the many streams which flow along the bottoms of the many deep and wide valleys.

AREA TRAVERSED

My route lay to the west of the Lewis river, on and in the vicinity of what is generally known as the Dalton trail—that is, up the valleys of the Chilcat and Klahina or Tlehini rivers, over the summit of the Coast or Chilcat range, and down a wide and continuous valley which, after being occupied in succession by parts of several streams, forks, the easterly portion forming the valley of the Nordenskiold river, which joins the Yukon a short distance above Five-fingers rapids, while the westerly valley passes northward by Aishihik lake to Nisling river, down that river to White river, and thence down the White to the point where it flows into the Yukon river.

In addition to the trip outlined, a short time was spent farther north on the Klondike river and its tributaries.

PHYSIOGRAPHIC FEATURES

Toward the south this country is a mass of steep, rocky, ungraded mountains, among which tower the giant peaks of Hubbard, Vancouver, Logan, and Saint Elias. These mountains lie to the westward of the great valley of the Lynn canal and Chilcat river, and form a range which would appear to be quite distinct from the granitic "Coast range," which forms the western wall of the continent farther south, in both Alaska and British Columbia. In order to distinguish this range more clearly, I propose for it the name "Chilcat range," associating it with one of the most powerful tribes of Indians on the Alaskan coast.

This range is bounded on the south and southwest by the Pacific ocean and toward the north and northeast by the great Chilcat-Alsek valley, which extends inland from the western arm of the Lynn canal, following more or less closely the line of contact of the granite to the northeast and the schists and limestones to the southwest. The average width of the range is between 80 and 100 miles.

Much of the range is buried in extensive snowfields, from which glaciers radiate in all directions, both toward the coast and toward the interior. A magnificent view of this country was obtained last summer from the summit of Farview mountain, a high peak southwest of Aishihik lake, and it presented the appearance of a vast white plain, through which the higher peaks rose in dark relief, mount Saint Elias appearing for a few moments from beneath the clouds. It is thus a vast snow-clad plateau, lying close to the Pacific coast, in one of the regions of greatest precipitation on the American continent.

Farther north the country is also mountainous, but the mountains are much more rounded, their slopes are easier, and their sides show comparatively few broken, ungraded cliffs. As a rule, they rise from 3,000 to 4,000 feet above the bottoms of the deeper intervening valleys. Standing on one of the summits, a great number of similar mountains may be seen on every side, all about the same height and probably cut out of the same extensive pre-Tertiary peneplain.

Lakes, in some cases of large size, lie in the bottoms of the valleys;

but, as far as my observations went, they are confined exclusively to those parts of the country which have been more or less completely covered by glaciers during the Pleistocene epoch. Beyond the limits of the glaciated region no lakes were seen.

Glacial Features

EXTENT OF THE SNOW AND ICE

While the Chilcat mountains are almost buried in snow throughout the year, very little snow is to be seen in summer on this "interior plateau," and any small glaciers that do exist are in some of the higher mountains close to the Chilcat range.

Though the ice-fields of the present day are confined almost entirely to the Chilcat mountains, the ice-fields of the Glacial period were much more extensive, for they spread northward as far as Five-fingers rapids on the Lewis river and to a short distance beyond Aishihik lake in the Aishihik valley. The northern limit of glaciation is not by any means an approximately straight line, for it indicates the lengths to which the glaciers filled the valleys rather than the even margin of a great confluent ice-sheet. The higher mountains rose above the level of the ice, just as they do at the present time in the Chilcat range, and small glaciers moved down their sides to join the larger glaciers in the valleys.

The Chilcat-Alsek valley gives a beautiful idea of the former depth or thickness of the ice. The bottom of the valley is almost flat, and the sides rise in gentle willow-covered slopes for 2,000 feet or more to the foot of the ungraded rocky peaks on either hand. Rock is everywhere exposed above this line, while below it rock exposures are comparatively rare, and the country is underlain by a loose unassorted till, on which willows and dwarf birches grow in dense thickets. As seen from the bottom of the valley, the upper limit of the willow-covered slope forms a fairly regular line along the sides of the mountains, and indicates approximately the depth to which the ice-sheet filled the valley, a depth which here varied from 2,000 to 3,000 feet. Above this line the higher mountains rise in broken, jagged peaks, while any lower mountains which do not rise above the level of the top of the till have their summits evenly rounded and unbroken.

THE TILL

The till which fills the bottom of this valley, often to depths of 100 feet or more, is a mass of unassorted material, in part local and in part derived from a distance. It contains pebbles and boulders, usually more or less rounded in shape, some of which are striated while the great majority are smooth and without glacial markings. In general character it is very similar to the till which underlies so much of the plains of northwestern Canada between the edge of the Archean nucleus and the Rocky mountains. Similar till was found to underlie the bottoms and sides of most of the valleys everywhere throughout the glaciated area in the Yukon district, having evidently been formed as a ground moraine beneath the great sheets of ice.

STRIATION

Striated rock surfaces were not very often seen, for where the rock is exposed it has usually become rough through weathering, but they were recognized in a few places on the interior plateau, and in every instance they indicated a direction of ice-movement motion from the coast toward the interior or essentially simply a wider extension of the glacial conditions which exist in the region at the present time. In this extension toward the interior the ice for the most part followed the great valleys which trench the surface of the country in a general north-and-south direction, and therefore the movement of the ice was generally northward.

Close to the coast the glaciers flowed seaward and filled the many deep valleys which descend from the mountains to the Pacific ocean. In the Skagway valley the White Pass railroad while constructing its line has cut a notch along a rocky hillside which has been beautifully smoothed and scored by such a glacier.

MORAINES

Lateral moraines occasionally form conspicuous features along the sides of the mountains, often running as long, narrow lines of boulders or transported material, swaying slightly up and down with the irregularities of the surface, and in places running into water-worn terraces where some small stream has thrown its load of gravel against the side of the glacier. A very well marked moraine of this character extends along the west side of the valley of Aishihik lake at about 1,500 feet above the water. It is a fairly regular ridge of boulders, along the crest of which, in some places, runs the horse trail from Fort Selkirk southward to Pyramid harbor. Above it the surface of the mountain consists of a fairly even, regular incline of decomposed rock, while below it is a till-covered slope, often broken into very lumpy, irregular hills. Lateral moraines were also traced down the side of a deep valley northwest of Aishihik lake as well as in some other places.

Terminal moraines were recognized in a few places, but they scarcely formed as conspicuous features as one would have been inclined to expect. From lake Aishihik northward for about 12 miles in the bottom of the valley is a terminal moraine area, represented in places by irregular hills of boulders, which was formed at the foot of the Aishihik lobe of the great ice-sheet when it had reached its extreme northern limit. The low stony hills east of the Hoochi lakes represent another moraine, while the stony hills at the mouth of the west branch of Nordenskiold river are clearly morainic in character; but they also show many signs of water action, and merge into the extensive pitted plain or terrace which extends along the banks of the Lewis river from the mouth of the Nordenskiold to Rink rapids.

TERRACES

The classes.—The terraces occurring in this region are of two kinds, namely, *stream terraces* and *lake terraces.*

Stream terraces.—Stream terraces have chiefly been formed by torrential rivers, loaded with detritus, flowing from the feet of the glaciers, and are most conspicuous in the larger valleys beyond the limits of the glaciated area, as, for instance, in the valleys of Lewis and Nisling rivers; but as the glaciers diminished in size and their fronts retired up the valleys, gravels and sands were deposited in the bottoms of the valleys which had previously been occupied by the ice, and thus terraces were formed on the low lands in the region which had been covered with glaciers.

Lake terraces.—Lake terraces are confined exclusively to the glaciated area, none having been recognized beyond the northern limits to which the vast ice-sheets of the Glacial period extended. They usually consist of fine sand, silt, or rock flour, which is often of whitish color and commonly has the appearance of the finer material carried down into bodies of quiet water by glacial streams. These terraces sometimes extend 2,000 feet or more up the sides of the mountains, especially in wider parts of some of the great valleys which traverse the country. Such terraces are beautifully shown on the sides of the mountains around lake Dezedeash. There can be no doubt that the outlets to the valley were filled with ice, and that the deep lake which existed here, around the shores of which the terraces of white silt were formed, was in part walled in by the fronts of glaciers.

Similar terraces were seen in many other places, and often several would descend in regular series, until it was difficult to distinguish the lowest from the higher and finer of the stream terraces. It is confidently believed, however, that all the white silt terraces in that portion of the Yukon district examined were formed in ice-dammed lakes and furnish no evidence whatever of marine conditions or of recent submergence of the land. Any regularity in height of the highest terraces is easily accounted for by the moderately regular average thickness of the ice-sheet when the lakes were in existence.

IN THE DAWSON DISTRICT

As small glaciers now exist in the valleys of the mountains north of the Chilcat range, so small glaciers formerly existed in some of the mountain valleys north of the main ice-sheet of the Glacial period. Such glaciers existed in the valleys of Eldorado and Bonanza creeks, near Dawson, and flowed down these valleys at least to some point below the confluence of the two creeks. Beautiful glacial striæ were seen on the hard quartzose rocks at the mouth of Big Skookum gulch, on the west side of Bonanza creek, which had been made by this glacier, furnishing indisputable evidence of its presence. A lateral moraine of this glacier, often containing pebbles and small boulders of distinct glacial shapes, extends along the side of the valley from 150 to 200 feet above the creek, and in it are some of the rich bench claims on Eldorado hill and at French gulch, and the sand and gravel in the bottom of the valley is well rounded, but roughly assorted material, such as is constantly washed down and distributed by glacial streams.

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PRE-CAMBRIAN FOSSILIFEROUS FORMATIONS

BY CHARLES D. WALCOTT

(Read before the Society December 30, 1898)

CONTENTS

INTRODUCTION

The base of the Paleozoic and of the Cambrian has been placed at the lowest known limit of the Olenellus fauna, all clastic rocks beneath being referred to the Algonkian,* a name given to the period embracing the time of the deposition of those clastic rocks which are older than the Cambrian.† The base of the Algonkian is the lowest of the recog-

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* Bull. U. S. Geol. Survey, no. 81, 1891, p. 362.

† Tenth Ann. Report U. S. Geol. Survey, 1890, p. 66.

nizable clastic rocks. This base is easily recognized beneath the Belt series of rocks in Montana, in the Grand Canyon region of Arizona, in portions of the Lake Superior region, and in eastern Newfoundland, as there are great unconformities between the Algonkian and the Archean, above which the clastic rocks are clearly defined. In other regions, however, the delimitation of the Algonkian and the Archean is very difficult. The basal plain of the Algonkian is obscured by volcanic rocks which, with the clastics, have been so altered and folded that it is practically impossible to differentiate them from the fundamental Archean complex. Frequently areas of rocks are met which can not with certainty be placed either with the Algonkian or with the Archean. The difficulty of defining in all areas the exact line of separation between the Algonkian and the Archean is not peculiar to this horizon, as intermediate beds are to be found between the Algonkian and the Cambrian, the Cambrian and the Ordovician, and so on.

Under the definition that all clastics older than the Cambrian are to be included in the Algonkian, the rocks of the Belt terrane of Montana, the Grand Canyon series of Arizona, the Llano series of Texas, and the Avalon terrane of Newfoundland are all clearly Algonkian.

Geological Notes

BELT TERRANE

Literature of the subject.—Dr F. V. Hayden first described, in 1860, the strata now referred to the Belt terrane.* In his Fifth and Sixth Annual Reports of Progress† he refers the same formation to the Lower Silurian as a portion of the "Potsdam" series, considering them an unconformable downward extension of the Paleozoic series.

The Belt rocks were also described and partial sections given by Grinnell and Dana, in 1875, from the vicinity of Fort Logan and White Sulphur Springs.‡ Later, when reporting the results of Dr A. C. Peale's field work, Dr Hayden refers to the "East Gallatin group" § as a name given by Dr Peale to the slates, sandstones, and impure limestones beneath the fossiliferous Cambrian rocks. Again, in the same connection, reference is made by him to the East Gallatin group as probably middle Cambrian.||

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* Exploration of the Yellowstone and Missouri rivers, 1860, p. 91.

† Preliminary Report U. S. Geol. Survey, Montana, 1872, p. 140; Sixth Ann. Report U. S. Geol. Survey of the Territories, 1873, pp. 72, 73.

‡ Reconnaissance from Carroll, Montana, to Yellowstone Park, U. S. War Dept., Washington, 1876, p. 116.

§ Sixth Ann. Report U. S. Geol. Survey, 1885, p. 50.

|| Seventh Ann. Report U. S. Geol. Survey, 1888, p. 86.

Dr J. S. Newberry crossed the Belt mountains in 1883 and noted the Cambrian (?) slates, which he correlated with the strata cut by Prickly Pear canyon on the west side of the Missouri river, also with the formation beneath the "Potsdam" in the Wasatch mountains near Salt Lake City and in the canyon of the Colorado.*

In 1886 Professor W. M. Davis described the Belt Mountain rocks as "a vast series of lower Cambrian barren slates, at least 10,000 to 15,000 feet thick at many points." His sections show the fossiliferous Cambrian beds conformable to the Belt Mountain slates.† Subsequently Dr A. C. Peale described the "Belt formation" as it occurs near Three Forks, Montana,‡ the same formation that he had called the East Gallatin group in 1884,§ when a thickness of 2,300 feet was carefully measured and the series considered to be of Cambrian age. Dr Peale in 1893 tentatively referred the Belt formation to the Algonkian on account of the absence of any fossil remains, the metamorphosed condition of the Belt rocks, and the existence of the unconformity between the Cambrian Flathead quartzite and the Belt beds below. This unconformity he considered as one caused by subsidence. He states: ||

> "There is no doubt that after the Belt formation was deposited there was an orographic movement by which the Archean area of nearly the entire region represented on our map south of the Gallatin and Three Forks was submerged just prior to the beginning of the Cambrian, before the Flathead quartzite was deposited. Whether this movement occurred immediately after the laying down of the Belt beds or after an interval is of course the question to be decided, and the decision can not be positively reached with the meager data now at hand. I am inclined to think that the subsidence of the Archean continent (or possibly islands) began with the first accumulation of the sediments that formed the lower portion of these beds and was coincident with their deposition throughout the entire period. It may have been succeeded by an emergence of the land area for a brief period, but the probability is that the interruption to the downward movement, if it occurred, was slight. Next, the widespread pre-Cambrian subsidence preceding the formation of the Flathead quartzite took place, and the Cambrian sea covered large areas that had hitherto been above the sealevel. There is a marked difference in the character of the beds of the two groups. Little, if any, induration is seen in the Flathead formation, while the Belt beds are so altered in most cases as to resemble closely the metamorphic crystalline rocks which underlie them, and from the breaking down of which they were derived. Notwithstanding the metamorphism, there is no mistaking their sedimentary character."

In 1896 Dr Peale, in describing the Belt formation, says:

> "It is possible that further investigation may result in the reference of this for-

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*Ann. Report N. Y. Academy of Science, vol. III, 1884, p. 249.

†Tenth Census, vol. XV, Mining Industries, 1886, pp. 697, 700, 702.

‡Bull. U. S. Geol. Survey, no. 110, 1893, pp. 16–20.

§Sixth Ann. Report U. S. Geol. Survey, 1885, p. 50.

|| Bull. U. S. Geol. Survey, no. 110, 1893, p. 19.

mation to the lower part of the Cambrian. At present, however, it is referred provisionally to the Algonkian." *

When summing up the results of the study of the Montana Algonkian rocks, Professor C. R. Van Hise says: †

> "There is also in this region, as shown by the work of Davis and Peale, a great series of unaltered strata which are probably Algonkian. This series is a downward succession of barren slates below the fossiliferous Cambrian, and, if Algonkian, is the uppermost division and equivalent to the upper Algonkian of the Wasatch. Peale's results indicate that while there is no actual unconformity, there is a change of physical conditions, a subsidence, and perhaps a real time break between the Cambrian and Algonkian. Nowhere yet have the unaltered barren slates and the more crystalline series of clastic origin been found in contact. Between the slates and the Archean gneisses is a great unconformity, and there is little doubt, when the unaltered series is carried over to the vertical limestones, quartzites, and quartz-schists that it will be found to rest upon them unconformably. There is, then, in this region probably two series of Algonkian rocks—one almost completely unaltered, the other thoroughly crystalline, and both of great thickness."

Brief reference is made to the Belt beds by Messrs Iddings and Weed in 1894,‡ where they are provisionally assigned to the Algonkian. In 1896 Messrs Weed and Pirsson described with considerable detail the Belt rocks as they occur in the Castle Mountain mining district of Montana, noting the various formations of which the terrane is there composed and showing the areal distribution on a geological map of the district. In this work the authors referred them to the Algonkian. §

In the Little Belt Mountain folio of the Geologic Atlas of the United States, now in press, Mr W. H. Weed separates the basal quartzite of the Belt formation as the Neihart quartzite, the upper portions of the series being mapped as the Belt shale formations of the Algonkian; the various formations composing this group are described in the text.

Author's investigations.—During the summer of 1895 I drove from Neihart to Townsend with Mr Weed, crossing the Little Belt and Big Belt mountains. The observations thus made led me to visit the region again in 1898 and make a general study of the pre-Cambrian rocks of the Big and Little Belt mountains and of the exposures of the Prickly Pear Valley area northwest and southeast of Helena. A visit was also made to the section on the Gallatin river, and special attention was given to the study of the relations of the Flathead Cambrian sandstones to the subjacent Belt formations. In part of the latter work I was accompanied

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* Geologic Atlas of the U. S., Three Forks folio, 1896, p. 2 of text.

† Bull. U. S. Geol. Survey, no. 86, 1892, p. 286.

‡ Geologic Atlas of the U. S., Livingston folio, 1894, p. 2 of text.

§ Bull. U. S. Geol. Survey, no. 139, 1896, pp. 26 and 32 et seq.

by Mr Leon S. Griswold, who was assisting Mr Weed in mapping the areal geology about Helena.

The results of my investigations were the discovery of a great stratigraphic unconformity between the Cambrian and the Belt formations; that the Belt terrane was divisible into several formations, and that fossils occurred in the Greyson shales nearly 7,000 feet beneath the highest beds of the Belt terrane.

The rocks of the Belt terrane are widely distributed in central Montana, the best sections being exposed in the Big Belt and Little Belt mountains, in Meagher and Broadwater counties. They extend to the north in Cascade, to the west in Lewis and Clarke and Jefferson counties, and to the south in Gallatin, Park, and Sweetwater counties, in all covering a known area of more than 6,000 square miles. Throughout this area the Cambrian rocks rest unconformably on different members composing the Belt terrane. The general outline of the areal distribution of the Belt rocks is shown on the accompanying sketch map, figure 1, prepared from data furnished by Mr W. H. Weed.

The principal members of the Belt terrane are as follows:

Marsh shales	300	feet.
Helena limestone	2,400	"
Empire shales	600	"
Spokane shales	1,500	"
Greyson shales	3,000	"
Newland limestone	2,000	"
Chamberlain shales	1,500	"
Neihart quartzite and sandstone	700	"
	12,000	feet.

Neihart quartzite and sandstone.—In this formation are included the reddish, coarse sandstones, with interbedded dark greenish layers of fine grained sandstone and shale, beneath the Chamberlain shales. The lower 400 feet of the formation is a massive, sometimes cross-bedded quartzite, which, in some of its members, where unaltered, is a compact, hard sandstone. The prevailing color is pinkish gray on the freshly exposed surface, with dark and iron-stained weathered surface. Occasional layers of a fine conglomerate occur in some portions near the contact with the gneiss.

This formation was named by Mr Weed from its occurrence at the type locality on Neihart mountain, where the quartzite and sandstones are in contact with the gneiss, and dip to the southeast, crossing Belt creek and passing beneath the superjacent formation in the canyons of Sawmill and Chamberlain creeks.

The thickness of the formation, as measured by Mr Weed, is 700 feet.

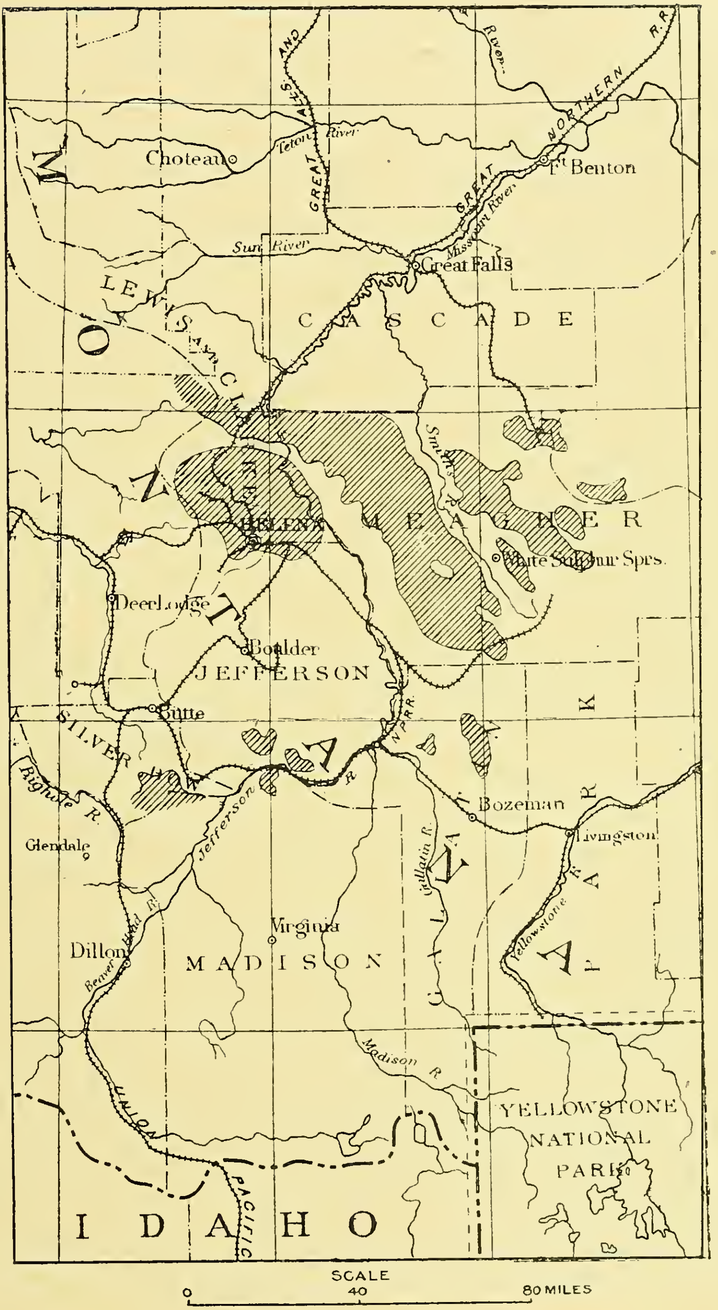

FIGURE 1.—*Distribution of Belt Terrane in Montana as shown by shaded Areas.*

Chamberlain shales.—This formation is composed of a series of dark silicious and in places arenaceous shales. Ripple-marks, mud-flows, and sun-cracks were occasionally seen, but no traces of life were observed. The dark shales frequently form low cliffs along the canyon side, near the beds of the streams.

The typical localities are on the ridges between Chamberlain and Sawmill creeks, southeast of Neihart. Estimated thickness, 1,500 feet.

Newland limestone.—At the typical locality on Newland creek the limestones are thin bedded, the layers averaging from 2 to 6 inches, with shaly partings of variable thickness between them. In the section in Sawmill canyon, near Neihart, the layers are somewhat thicker, more impure, and with a greater number of beds of interbedded shale. The prevailing color of the limestone is dark bluish-gray on fresh fracture, and buff to straw color on the weathered surface. The limestones are hard, many of the layers breaking with a conchoidal fracture, and some of the purer portions give off a bituminous odor when crushed with the hammer. The thickness of the formation is estimated at 2,000 feet. A careful search at several localities failed to bring to light any traces of fossils.

The typical localities of the Newland limestone are on Newland creek, 10 miles north of White Sulphur springs, and on Sawmill creek, 4 miles south of Neihart.

Greyson shales.—Dark colored, coarse, silicious and arenaceous shales, passing above into bluish-gray, almost fissile shales, which when broken up weather to a light gray fissile shale, resembling a poor quality of porcelain. These in turn are succeeded by dark gray silicious and arenaceous shales, with interbedded bands of buff-colored sandy shales and occasional layers of hard, compact, greenish gray and drab silicious rock. At the base of this series, in Deep Creek canyon, a belt of quartzites occurs, interbedded with shales, the base of the quartzites showing 10 feet of interformational conglomerates, composed of sand and pebbles up to 8 inches in diameter, and derived from the subjacent Belt rocks.

The conglomerates and the quartzites are about 100 feet in thickness. This local deposit does not occur at the same relative horizon in the Sawmill Creek section, near Neihart.

Fossils were found in the lower part of this series in Sawmill canyon and near the mouth of Deep Creek canyon, just above Glenwood post-office. They include numerous trails, *Helminthoidichnites? neihartensis, H.? spiralis, H. meeki. Planalites corrugatus, P. superbus*, and many fragments of crustaceans referred to the Merostoma. Only one form, *Beltina danai*, is named.

The typical section is on the side of the ridge between Greyson and Deep creeks, where the estimated thickness is 3,000 feet.

Spokane shales.—The Spokane shales occur as massive beds of silicious and arenaceous shales of a deep-red color. The arenaceous shaly portions frequently thicken up into thin layers of sandstone. The shales break down on exposure, but they are usually sufficiently firm to resist erosion and form strongly marked slopes and cliffs. In nearly all of the contacts between the Belt terrane and the Cambrian they form the upper member of the Belt; in but one case known to me do the subjacent Greyson shales come into contact with the Cambrian sandstones; this is on Belt and O'Brien creeks, near Neihart. In some localities, as at Sawmill canyon, there is but a comparatively thin band of the Spokane shales between the Greyson shales and the Cambrian.

The most characteristic locality of these shales is in the Spokane hills, 15 miles east of Helena, although the base of the formation is not there exposed. The estimated thickness of the Spokane shales in Whites canyon, 10 miles east of the Spokane hills, is 1,500 feet.

Empire shales.—These are greenish gray, massively bedded, banded, silicious shales, forming the basal portion of the formation above the granite in the vicinity of Empire and at Marysville. They are finely exposed in the Drum Lummon mine, at Marysville, and along the ridge north of Empire, between Lost Horse gulch and Prickly Pear creek.

The type localities are on the ridge north of Empire and in the canyon walls just below Marysville. The estimated thickness is 600 feet.

Helena limestone.—The Helena limestone formation is composed of more or less impure bluish gray and gray limestone, in thick layers, which weathers to a buff and in many places to a light gray color. Irregular bands of broken oölitic and concretionary limestone occur at various horizons. Bands of dark and gray silicious shale and greenish and purplish argillaceous shale are interbedded in the limestones. These bands are from half an inch to several feet in thickness. There are also beds of thinner bedded limestones, especially toward the top of the formation.

The name "Helena limestone" is given on account of the occurrence of the limestone in the upper part of the city of Helena and on the hill slopes to the east, where the estimated thickness is 2,400 feet.

Marsh shales.—At Helena there is a thickness of about 250 feet of shales and thin bedded sandstones of the Belt terrane above the Helena limestone and beneath the Cambrian sandstones. The same bed, on the north side of Mount Helena, is reduced to 75 feet in thickness, but to the northwest the formation increases in thickness to 300 feet or more. The reddish shales are prominent on Greenhorn mountain and beyond to the canyon of Little Prickly Pear creek, and also to the north at Marsh creek. On the ridge between the two creeks there is an excellent section, and the name "Marsh shales" is given to this, the topmost formation of the

Belt terrane. The estimated thickness of the formation in the type locality is 300 feet.

The only section of the Belt terrane measured in detail is that studied by Mr Weed on Belt creek, near Neihart. It is less than half the thickness of the section in the Big Belt mountains and westward to Helena. The formation names have been inserted in Mr Weed's section as nearly as I could determine the horizons by comparison with other sections.

Section of the Belt terrane.—This section, which is exposed on Belt creek, south of Neihart, Montana, and from which the measurements were made, is as follows:

	Feet	Feet
CAMBRIAN:		
Cambrian sandstone, dark red, containing white pebbles with quite ferruginous matrix; only 40 feet exposed, the bed occurring in the creek channel a quarter of a mile below the forks of the stream	100	
		100
PLANE OF UNCONFORMITY.		
SPOKANE SHALES:		
Red shales	200	
Red shales—laminated, brittle, and quite hard	10	
		210
GREYSON SHALES:		
Shales generally gray, rarely exposed, and forming densely wooded slopes	700	
Gray sericitic shale, locally disturbed by a horizontal sheet of minette	170	
Shales exposed in wall on west side of canyon; thinly bedded slaty shales carrying limestone and fossils in the shaly slates, 2 miles to the southeast	60	
No exposure	25	
		955
NEWLAND LIMESTONE:		
Massive, block-jointed limestones, blue on fresh fracture and weathering an earthy brown; dip, 20 degrees south	15	
Calcareous shales and thinly bedded limestone; beds hidden by talus	200	
Limestones with massive outcrop, blue on fresh fracture, weathering an earthy buff color	60	
Slates (minette intrusion)	125	
Limestone, fissile and slaty	18	
Massively bedded slate	15	
Impure limestone	5	
Black or gray slate with glistening surface; dip, 30 degrees	15	
Trachyte intrusion, which disturbs normal dip of strata.		
Limestone and slate, not well exposed	30	
Minette sheet	6	

	Feet	Feet
Limestones and shale	20	
Shales, slaty, in part indurated; dip, 20 degrees south; strike, south 80 degrees east	15	
Slaty shale, gray in color and well indurated	30	
Limestone in 3-foot beds of dark gray color, with crystalline markings	8	562
CHAMBERLAIN SHALES:		
Gray shale, no massive exposure was seen [*]	1,095	
Black shale, exposure being a quarter of a mile below a western branch of the creek	363	
Massively bedded black shale; dip, 20 degrees upstream	40	
No exposure	190	
Black shale	40	
Black crumbly shale; dip, 14 degrees	54	
Black shales	229	
Thinly bedded and fissile quartzite	5	
Black shale, somewhat slaty, carrying beds of green quartzite	40	
Shale, not exposed	22	2,078
NEIHART QUARTZITE:		
Quartzite	2	
Micaceous shale with fucoidal markings, resembling Cambrian	1	
Quartzite, greenish in color, occurring in beds 6 to 8 inches thick, with intervening black carbonaceous shale	7	
No exposure	95	
Shales, micaceous, dark colored, generally green and carrying thinly bedded quartzites, so that the entire series might be classed as quartzite	15	
No exposure	170	
Green micaceous shale in micaceous quartzite, occurring in beds 4 to 12 inches in thickness, in alternate layers	8	
Micaceous shales resting upon basal quartzites	104	
Quartzite series, forming base of formation	300	702
Total section		4,607

AGE OF CAMBRIAN BEDS RESTING ON BELT TERRANE

The fauna of the shales and limestones immediately above the Flathead sandstone is of middle Cambrian age, and, as shown in a number of sections, the fossils in the lowest horizons belong to the oldest part of the middle Cambrian fauna, as the latter occurs a short distance above the Olenellus horizon in Utah and Nevada. Near Logan, on East Gallatin river, the fauna was found in the sandstone about 25 feet above the contact with the Belt rocks. The Cambrian sandstone is formed of beach sand,

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[*] Probably a considerable portion of this should be included in Newland limestone series.

usually washed clean by the sea as it advanced on the land, not a sand of river and tidal deposition mixed with mud, such as forms many of the sandstones of the Belt terrane, notably those of the Spokane shales formation.

Absence of lower Cambrian rocks and fauna is accounted for by the fact that that portion of the continent now covered by the Belt and associated middle and upper Cambrian rocks was a land surface during lower Cambrian time.

UNCONFORMITY BETWEEN BELT TERRANE AND CAMBRIAN

Extent and character of recognized contacts.—The contact of the Flathead Cambrian sandstones with the rocks of the Belt terrane may be observed along a great extent of outcrop on the eastern, southern, and western sides of the Little Belt and Big Belt mountains. Fully 200 miles or more of outcrop may be followed, along which frequent contacts may be observed. On the eastern side, in the vicinity of Neihart, the unconformity between the Cambrian and underlying Belt terrane is clearly evident, though the angular unconformity is generally slight and has been recognized only on Sawmill creek. Four miles north of Neihart the Cambrian rests on a nearly level surface of crystalline schists. West of Neihart it rests on the Neihart quartzites. On O'Brien creek, a few miles southwest of the town, it rests on black shales (Chamberlain shales), of which there is less than 300 feet in thickness between the Cambrian and the top of the Neihart quartzite. On Chamberlain creek and upper Belt creek, 6 miles southeast of Neihart, the Cambrian rests on the Greyson shales, while along the stage road up Sawmill creek it is superimposed on the red Spokane shales. The only exposures on the eastern slope of the Little Belt range, those of the south fork of the Judith, show the Cambrian resting on the drab Greyson shales. These are the only instances known where the red Spokane shales are wanting beneath the Cambrian. Whether the shoreline conditions, which are known to have existed near Neihart during the period when the Belt terrane was formed, caused a wedging out of the beds to the north, so that the Cambrian rests on different horizons at this locality, or whether pre-Cambrian erosion was extensive enough to pare down the exposed edges of the beds, is not certain from the evidence, though the latter view seems improbable. Similar conditions prevailed southward in the Bridger range.

In the north end of the Bridger range, east of Gallatin valley, the Cambrian is seen resting on the Belt terrane, which at this locality does not show its typical development, but consists largely of coarse sandstones and grits composed of Archean debris. In the south end of this range, but a few miles distant from the former exposures, the Belt terrane is entirely wanting, and the Cambrian rests directly on the Archean schists, as it does at Neihart. The character of the Belt beds indicates, moreover, that the Cambrian overlaps the Belt shoreline. Forty miles southeast of Neihart, in the Deep Creek and Greyson Creek sections, on the southwestern slope of the Big Belt mountains, the Flathead rests on the Spokane shales, but at a higher horizon than at the head of Sawmill canyon. Twenty-two miles north-northeast of Deep creek, in Whites canyon, the full thickness of the Greyson shale and also about 1,000 feet of the Helena limestone occur beneath the Cambrian sandstones.

Crossing the valley of the Missouri river from Whites canyon directly westward 10 miles to the Spokane hills, on the west side of the river, one finds a syncline of Cambrian resting directly on the red Spokane shales. Continuing westward on the same line to the city of Helena, a distance of 14 miles, the Cambrian sandstones are found resting on shales 250 feet above the Helena limestone, or fully 3,000 feet above the contact horizon in the Spokane hills. Following the line of contact to the southeast for 1 mile, the Cambrian sandstones may be seen resting directly on the massive beds of the Helena limestone, a slight unconformity occurring at the point of contact, as shown by figure 3. A mile farther southeast there are 6 feet of shale above the limestone, a slight unconformity being shown between it and the Cambrian. The section east from Helena extends downward through some 2,000 feet or more of limestone and interbedded shales and several hundred feet of silicious, green-

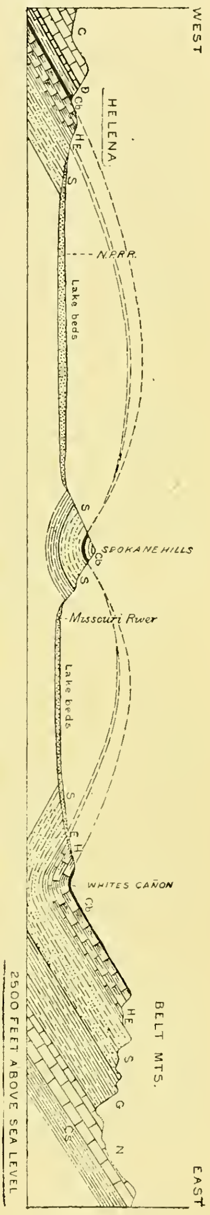

FIGURE 2.—*Diagrammatic Section showing Relations between Cambrian and Belt Terrane.*

The area indicated extends from the west of Helena across the Prickly Pear valley to the Spokane hills and the Missouri valley to the Big Belt mountains. The thinning out of the Helena limestones (*H*) and the Empire shale (*E*), both from the east and from the west, toward the Spokane hills, is shown by the dotted lines.

C, Carboniferous; *D*, Devonian; *Cb*, Cambrian; *H*, Helena limestone; *E*, Empire shales; *S*, Spokane shales; *G*, Grayson shales; *N*, Newland limestone; *Cs*, Chamberlain shale.

ish shales before reaching the red Spokane shales, which underlie the Cambrian in the Spokane hills.

The relations of the Cambrian and the subjacent Belt terrane on the line of the section from Helena eastward across the Spokane hills to the Big Belt mountains are indicated in the diagrammatic section, figure 2.

Northwest of Helena the contact between the Cambrian and the Belt terrane is followed to the crossing of Little Prickly Pear creek, 6 miles west of Marysville. The Helena limestone outcrops all along the hills and gulches, and at Marysville the subjacent Empire shales occur beneath the limestone. West of the Marysville Canyon area the silicious beds dip from 10 to 15 degrees to the northwest and pass above into the Helena limestone series, on which rest the Marsh shales. Crossing east-northeast, to the Gates of the Mountain, on the Missouri, 18 miles north of Helena, one finds the Cambrian sandstones resting on the red Spokane shales. This contact is again well shown on the eastern side of the Missouri river, on the road to Beaver creek. On Beaver creek the Cambrian rests directly on the Spokane shales, which, with the Grayson shales, constitute a thickness of several thousand feet between the Newland limestone and the base of the Cambrian. The contact at the crossing of Soap and Trout creeks, to the northeast, is essentially the same as at Beaver creek and the Spokane hills, although there is a variation in the beds of the Greyson, which come in contact with the Cambrian.

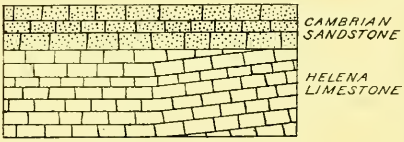

FIGURE 3.—*Unconformity between Helena Limestone and Cambrian Sandstones.*

The locality indicated is one mile southeast of Helena, Montana.

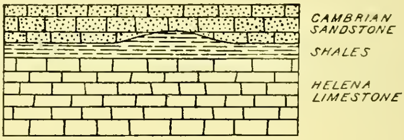

FIGURE 4.—*Unconformity between Marsh Shale and Cambrian Sandstone.*

The locality indicated is two miles southeast of Helena, Montana.

At most of the outcrops where the lower beds of the Flathead (Cambrian) sandstones come in contact with the Belt rocks the dip and strike of the two are usually conformable, so far as can be determined by measurement. This holds good all around the great Belt Mountain uplift. It is only when the contacts are examined in detail, as near Helena, that the minor unconformities are discovered (figures 3 and 4), and only when comparisons are made between sections at some distance from each other that the extent of the unconformity becomes apparent.

Explanation of apparent conformity.—The reason for the apparent conformity in strike and dip between the two groups appears to be as follows: In pre-Cambrian time the Belt rocks were elevated a little above the sea, and at the same time were slightly folded, so as to form low ridges. One of these ridges is now the base of the Spokane hills, where the Helena limestone and the upper portion of the Spokane shales were removed by erosion in pre-Cambrian or early Cambrian time. Usually there is very little, if any, trace of this pre-Cambrian erosion contained in the basal sandstones of the Cambrian. On Indian creek, however, west of Townsend, which is on the strike of the Spokane Hills uplift, the basal bed of the Cambrian is made up almost entirely of fragments of the subjacent Spokane shales. Fragments of these shales were also observed in the sandstones of the Cambrian in the Little Belt mountains near Wolsey postoffice. These illustrations are exceptional, the base of the Cambrian sandstone being formed usually of a clean sand, such as might be deposited where the sea was transgressing on the land.

The gentle quaquaversal uplift of the Belt rocks gave them a slight outward dip toward the advancing Cambrian sea, so that the sediments laid down on the Belt rocks were almost concentrically conformable to them. Subsequent orographic movements have elevated the Belt rocks into mountain ridges and have tipped back and in many instances folded the superjacent Cambrian rocks, but the original concentric conformity between the beds of the two series remains wherever the lines of outcrop are at right angles to the plane of erosion of the Cambrian sea which cut across the Belt rocks toward the center of uplift.

Extent of unconformity.—The extent of the unconformity between the Belt and the Cambrian may never be ascertained, as there is no section known where the sedimentation is unbroken from the Belt to the Cambrian. The greatest example of erosion is in the Spokane hills, where the Helena limestone, with its superjacent Marsh and subjacent Empire shales, has been removed (figure 2, page 211). In other localities the red Spokane shales have been very largely removed, but some of these are so far from the Spokane Hills section that it may be urged that they were not originally deposited in any greater thickness than is shown in the sections. The unconformity now known proves that in late Algonkian time an orographic movement raised the indurated sediments of the Belt terrane above sealevel, that folding of the Belt rocks formed ridges of considerable elevation, and that areal erosion and the Cambrian sea cut away in places from 3,000 to 4,000 feet of the upper formations of the Belt terrane before the sands that now form the middle Cambrian sandstones were deposited.

I think that an unconformity to the extent indicated is sufficient to

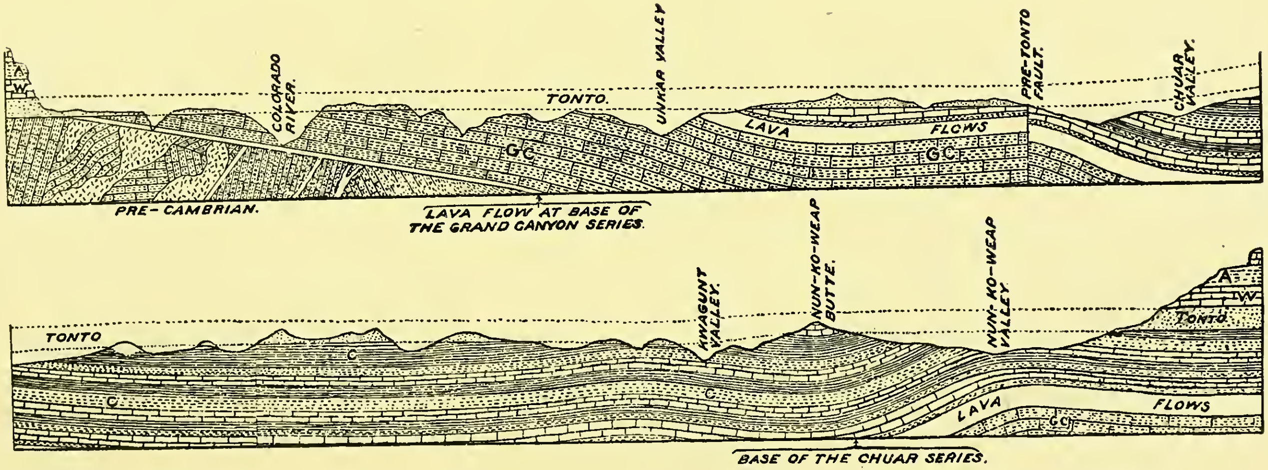

Figure 5.—*Section showing Unconformity between Algonkian and Cambrian Formations in the Grand Canyon of the Colorado.*

The section represented in this figure crosses the Grand Canyon series nearly at right angles to the strike of the beds as exposed in the Grand canyon of the Colorado, Arizona. Horizontal scale, 12,500 feet to the inch; vertical scale, about 8,500 feet to the inch.

The line of the section is shown on the geological map of the Grand canyon, published in the Fourteenth Annual Report of the U. S. Geological Survey, 1895, plate lx.

The Cambrian Tonto formation has been removed by erosion on the direct line of the section. It is present around the margins of the canyons, and its position is indicated in the figure by the dotted lines.

T, Tonto formation; *C*, Chuar terrane; *GC*, Unkar terrane. The strata which rest unconformably beneath *GC*, at the left of the figure, are pre-Cambrian, but not distinctly pre-Algonkian.

explain the absence of lower Cambrian rocks and fossils and to warrant our placing the Belt terrane in the pre-Cambrian Algonkian system of formations.

GRAND CANYON TERRANES

Composition and character.—The Algonkian formations composing the Grand Canyon series of Arizona differ materially, in the order of their succession, from the Belt series of formations; but the sedimentation is strikingly similar in many of the beds, especially those of the Chuar terrane. These embrace limestones, shales, and interbedded sandstones, which are of the same type lithologically as those of the Belt terrane in the Little Belt and Big Belt mountains.

The plane of unconformity between the Cambrian and the Algonkian formations is more marked than that between the Cambrian and the Belt in Montana. The plane of pre-Cambrian erosion cut across the entire Grand Canyon series and extended a long distance beyond, across the subjacent schists and granites. The extent of the unconformity is illustrated by figure 5.

Chuar terrane.—This section is arranged from the summit of the formations downward.* The limestone in the upper division of the section is 138 feet, while the limestone of the lower division is 147 feet, making a total thickness of limestone of 285 feet.

Upper Division:	Feet
1. Massive reddish brown sandstone, passing into shales below, with irregular layers of similar color, and containing numerous fragments of sandstone shale of lighter color	425
2. Alternating shales and limestone; traces of fossils occur in the lower portion of the shale; *Chuaria circularis* is the only species that has been defined	337
3. Gray Stromatopora (?) † limestone	8
4. Black argillaceous shale, with variegated shales below; on the slopes light drab, pea-green, vermilion, chocolate, maroon, and buff-colored shales of various shades alternate	740
5. Massive stratum of concretionary limestone, with sandstones and shales below; reddish brown sandy shale	190
Total thickness of upper division	1,700
Lower Division:	
1. Brown sandy shales, passing below into chocolate and dark argillaceous shales that pass below into alternating sandy and argillaceous shales, with thin belts of limestone from 6 inches to 4 feet in thickness; Stromatopora (?) limestone of 4 feet near base	625

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*This section is given in detail in the Fourteenth Ann. Report U. S. Geol. Survey, 1895, pp. 508–512.

† Probably a species of Cryptozoon.

	Feet
2. Chocolate-brown, dull, and yellowish green sandy and argillaceous shales, with sandstone in narrow bands and 21 feet of limestone in thin layers near the middle and base of the stratum	625
3. The sandstone and sandy shales become less prominent, the argillaceous and calcareous strata replacing them, 62 feet of limestone occurring in 522 feet of strata	522
4. Black argillaceous shale, with chocolate and greenish sandy and argillaceous shales beneath	100
5. Three feet of compact, mottled, buff limestone interbedded in 15 feet of brown sandy shale	18
6. Black, chocolate, and various colored sandy and argillaceous shales	830
7. Massive band of irregular, thinly bedded limestone, gray and buff, except near the chocolate-colored upper stratum, with thinly bedded limestones below; conchoidal fracture	50
8. Dark argillaceous shale, with a strongly marked band of a deep maroon color and drab, yellowish green, and dark or brownish black	450 to 650
Total thickness of lower division	3,420

Total thickness:

Upper division	1,700
Lower division	3,420
	5,120

Limestone in upper division	138
Limestone in lower division	147
	285

Unkar terrane.—This section is arranged from the summit of the formations downward.

	Feet	Feet
1. *a.* Massive beds of gray to reddish magnesian limestone, passing below into a calciferous sandrock	50 to 150	
b. Light gray shaly sandstone and irregular massive beds of yellowish brown sandstone	325	
		475
2. LAVA BEDS:		
a. Dark green basaltic rock, with a reddish tinge	100	
b. Layers of a reddish brown sandstone	8 to 10	
c. Solid, compact lava, of a dark green and reddish tinge	70	
d. A layer of sandstone, 1 foot in thickness, caps a massive flow of dark green lava	100	
e. A flow not unlike "*d*," and capped by a layer of sandstone 2 feet in thickness	70	
f. A layer of vesicular lava, with a thin stratum of sandstone at the summit	10	
g. Solid, compact lava, of a dark green and reddish tinge	175	
h. Reddish brown sandstone, compact and slightly metamorphosed toward the summit	15	

	Feet	Feet
i. This flow rarely forms a cliff, and the rocks crumble into a rather light olive-green coarse sand; thin beds of reddish brown sandstone occur in several places	250	
		800
3. Sandstones (upper):		
a. Shaly vermilion sandstones, with intercalated bands of a greenish gray, followed below by 700 feet of vermilion beds of a uniform character	1,730	
b. The vermilion sandstones of "*a*" pass into chocolate-colored sandstones underlain by 300 feet of friable sandstone and arenaceous and micaceous shale	1,500	
		3,230
4. Sandstones (lower):		
a. Compact quartzitic gray sandrock, 25 feet, with 65 feet of hard, compact sandstone	90	
b. Massive, compact, cliff-forming, brown, buff, and purplish-brown sandstone	1,200	
c. Reddish brown to vermilion, friable, shaly sandstone, with fine, silicious conglomerate (10 feet) at the base	830	
		2,120
5. Alternating beds of sandstone and limestone		69
6. Dark, compact basaltic lava in one massive, probably intrusive, flow		80
7. Light gray, compact, shaly limestone, with pinkish tinge between the laminæ		26
8. Silicious conglomerate, formed largely of pebbles derived from the upturned edges of the pre-Unkar strata, upon which it rests unconformably		30
Total thickness of Unkar terrane		6,830
Total thickness of Chuar terrane		5,120
Total thickness of Grand Canyon series		11,950

AGE OF CAMBRIAN BEDS RESTING ON GRAND CANYON SERIES

The fauna of the sandstones and shales at the summit of the Tonto sandstone, 290 feet above its base, is of middle Cambrian age and is of the same type as that of the shales of the Flathead formation above the Belt terrane, in Montana.

The Cambrian Tonto sandstone is essentially a beach deposit, and many of its beds are similar to those of the Flathead sandstone.

The absence of the lower Cambrian rocks and fauna is attributed to the fact that the portion of the continent now covered by the Grand Canyon formations and the associated Cambrian rocks was a land surface during lower Cambrian time.

UNCONFORMITY BETWEEN GRAND CANYON SERIES AND CAMBRIAN

Location of the contact.—The contact of the Tonto Cambrian sandstone with the rocks of the Chuar terrane is beautifully shown in the walls of the Grand Canyon proper, and also of the lateral canyons which enter it. As has already been mentioned, the plane of unconformity cuts across the pre-Cambrian rocks from the highest beds of the Chuar terrane to the base of the Unkar terrane and into the subjacent schists and granites. This is illustrated by figure 5.

Extent of unconformity.—The extent of the unconformity between the Chuar terrane and the Cambrian will probably never be fully ascertained. We now know that the highest beds of the Chuar terrane formed an island in the Cambrian sea which was more or less eroded prior to the deposition of the Cambrian beds over its summit, the basal beds of the Cambrian being deposited around its sides. The unconformity proves that an extended orographic movement took place prior to the pre-Cambrian erosion, and that the subsequent erosion must have been of comparatively long duration to produce the baselevel on which the Cambrian sediments were subsequently deposited.

LLANO SERIES OF TEXAS

In central Texas the basal sandstones of the Cambrian correspond, lithologically and by means of the middle Cambrian fauna in their upper beds, with the Tonto sandstones of the Grand Canyon section. They rest unconformably on a series of alternating shales, sandy shales, sandstones, and limestones, which are very much like those of the pre-Cambrian Grand Canyon series. Like the Grand Canyon series, the Llano rocks are almost unaltered, showing little more evidence of metamorphism than the overlying Cambrian and Carboniferous strata.

No systematic search for fossils has been made and none have been found, but on account of similarity in stratigraphic relations and lithologic characters between the Llano series and the Grand Canyon series the two have been correlated.*

AVALON TERRANE

The formations in general.—This terrane includes the formations between the basal beds of the Cambrian and the Archean gneisses of Newfoundland. In the summer of 1888 I made a rapid trip across the section from Saint John harbor to Topsail head, Conception bay, which gave me a clear impression of the general character and order of succession of the strata, but no details. For the latter it is necessary to refer to the reports of Dr Alexander Murray.

Dr T. S. Hunt gave the name Terranovan to the series of strata between the Laurentian gneisses and the fossiliferous strata of Cambrian

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*Am. Jour. Sci., vol. 28, 1884, pp. 431, 432. See also Professor Comstock's description in Second Ann. Report Geol. Survey of Texas for 1890, pp. 562, 563.

age.* Subsequently he restricted the name to the gneissic series † and did not consider the upper series. ‡

The name Avalon is now proposed on account of the typical development of the terrane on the peninsula of Avalon. It includes four principal formations, § designated as follows:

	Thickness in feet
Signal Hill	3,120
Momable	2,000
Torbay	3,300
Conception	2,950
	11,370

Signal Hill sandstone.—The typical localities are at Signal hill, Saint Johns harbor, Bay de Verde, New Perlican, and Baccalieu island.

	Feet
1. Red conglomerate, the pebbles of which are chiefly white quartz, but with occasional pebbles of brown or red jasper, syenite, or gneiss and slate; the pebbles vary in size from a pea to a 6-pound cannon ball	500
2. Dark red sandstone, hard and tough, in strong, massive, irregular beds, from 2 to 3 feet thick, passing into a fine conglomerate at the top; the whole reticulated with veins of white quartz	1,320
3. Greenish or gray fine grained sandstone, very hard, with conchoidal fracture; difficult to work, but used to a large extent as a building stone, in beds varying from 1 to 3 feet thick	1,300

Momable slates.—This series of slates is cut across by Momable bay, and is well shown at Saint Johns, Harbor Grace, Carbonear bay, Roberts bay and Northern bay.

	Feet
Dark brown or blackish slates of Saint Johns, with ripple mark very distinctly displayed upon some surfaces, and in which some obscure organic remains have been found resembling the fossils found in the Torbay formation, and another supposed to be the shelly casing of some description of Annelid (Arenicolites); the cleavage of this slate is sometimes very regular, oblique or at right angles to the bedding, but in parts it also cleaves parallel with the stratification; toward the top there are frequent layers of hard, fine grained, greenish sandstone interstratified, not usually more than 6 or 7 inches in thickness	2,000

Torbay slates.—At Torbay this series is finely shown. It covers a great extent of country in its broad extension from cape Saint Francis to cape Race, Saint Marys bay, and across to Conception bay.

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* Am. Jour. Sci., 3d ser., vol. 1, 1870, p. 87.

† Chem. and Geol. Essays, 1875, p. 194.

‡ Ibid., p. 244.

§ Geol. Survey Newfoundland, Reprint of Reports, 1881, pp. 145, 146. The distribution of the various formations is finely shown on the geological map of the peninsula of Avalon, Murray & Howley, 1881.

	Feet
Green, purple, pinkish, or red slates in frequent alternations; the texture of these slates is generally extremely fine, and in some cases they approach in hardness to jasper or chert; the fracture is often conchoidal, and the imperfect cleavage parallel with the bedding, but in many instances the rock has a good cleavage, oblique or at right angles to the stratification, and is well adapted for roofing purposes; the exposed surfaces weather for the most part to a yellowish white; the fossil forms, supposed to be of the genus Oldhamia, were found in these slates toward the top..............	3,300

Conception slates.—The various members of this formation are well shown at Topsail Head and at the head of Conception bay; also on the eastern side of Placentia bay.

	Feet
1. Slate conglomerate and slate without pebbles, the matrix of the conglomerate chiefly of a dark greenish color and trappean aspect, inclosing pebbles of quartz, many of which are white and some gray, syenite, red and brown jaspers, slate, and occasionally drab-colored or yellowish chert; vertical cleavage sometimes observable, and at times cutting indifferently through both pebbles and matrix, while at other times the pebbles are loosely imbedded and break out whole from a blow of the hammer..	1,650
2. Diorites, quartzites, and jaspery bands; some of the latter of a reddish color, with hard greenish slates; at Topsail there is probably some additional lower strata, and there is one very remarkable stratum or vein of vitreous white quartz, which runs parallel with the stratification and exposes a thickness of from 10 to 12 feet, but may be more, the unconformable rocks occupying the margin between it and the shore....	1,300

AGE OF CAMBRIAN BEDS RESTING ON AVALON TERRANE

The red and green slates near the base of the Cambrian section on Manuels brook carry the Olenellus fauna. Mr G. F. Matthew* is inclined to consider that some of the fossils found in the red and green slates below this horizon on Random sound are pre-Olenellus and of pre-Cambrian age. I do not think, however, that the published data are sufficient to prove that such is the case. Reference to this will be found in the discussion of the fossils found in pre-Cambrian rocks.

UNCONFORMITY BETWEEN AVALON TERRANE AND CAMBRIAN

Location and character of contacts.—As shown by the geological map of the peninsula of Avalon, 1881, the Cambrian rocks do not come in contact with the upper formations of the Avalon terrane. On the shores of Conception bay they rest against the Conception formation at the base of the Avalon terrane and overlap onto the Archean. About Saint Marys bay they are in unconformable contact with the Conception, Torbay, and

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* Trans. New York Acad. of Science, vol. xiv, 1895, p. 107.

Momable formations, and on Trinity bay with the base of the Signal Hill sandstones, the Momable, Torbay, and Conception formations. At no point are they shown in contact with the upper beds of the Signal Hill sandstones. The unconformity, like that of the Grand canyon of the Colorado, cuts across the entire Algonkian series, indicating profound orographic disturbance and long continued erosion prior to the deposition of the Cambrian rocks (figure 6).

Extent of unconformity.—It is impossible, from our present information, to determine the extent of the unconformity between the Cambrian formations of the Avalon terrane, as there is no one section where there is a transition from one to the other. The unconformity now known proves that a profound orographic movement raised the indurated sediments of the Avalon terrane above sealevel, that the formations were folded and faulted, and that subsequent erosion cut across the entire series from the highest beds of the Signal Hill sandstones to the Archean beneath. What formations existed above the Signal Hill sandstones and were removed by pre-Cambrian or post-Cambrian erosion is unknown.

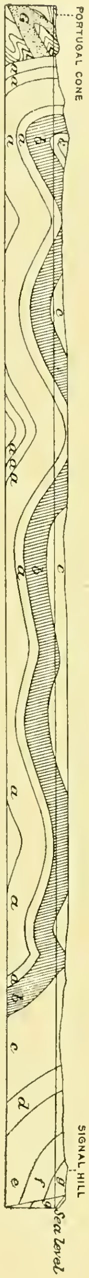

FIGURE 6.—*Diagrammatic Section from Signal Hill, Saint Johns Harbor, Portugal Cove, Conception Bay.*
aa, *bb*, Conception slates; *cc*, Torbay slates; *dd*, Momable slates; *e*, *f*, *g*, Signal Hill sandstones; *G*, Granite.
The Cambrian does not come in contact with the Avalon rocks in this section.

ALGONKIAN ROCKS OF THE LAKE SUPERIOR REGION

Table of pre-Cambrian rocks.—The Algonkian rocks of the Lake Superior region comprise a great series of sediments between the Cambrian and the Archean. The following tabulation (page 222) by Van Hise* illustrates the order of succession and the unconformities between the three upper members of the Algonkian terrane.

Keweenaw series.—The Keweenawan is now generally recognized as a series many thousands of feet thick, consisting of interbedded lava flows and water-deposited detrital material, derived chiefly from the contemporaneous igneous rocks. The volcanics are predominant in the lower part of the series, the interstratifications of the two are most frequent in

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* Bull. U. S. Geol. Survey, no. 86, 1892, p. 195.

Pre-Cambrian Rocks of the Lake Superior Region

		Western Ontario.	Northern Minnesota.	Michigan.			Michigan and Wisconsin.	Wisconsin.	Iowa, South Dakota, and southern Minnesota.
				Marquette.	Felch Mountain.	Menominee.	Penokee.		
Algonkian.	Keweenawan.	Nipigon.	Keweenawan.				Keweenawan.	Keweenewan.	
	Unconformity.	Unconformity.	Unconformity.				Unconformity.	Unconformity.	
	Upper Huronian.	Animikie and Upper Kaministiquia.	Animikie and Upper Vermilion.	Upper Marquette.		Western Menominee.	Penokee-Gogebic proper.	Chippewa quartzites. Baraboo quartzites.	Minnesota and Dakota quartzites surrounded by fossiliferous series.
	Unconformity.	Unconformity.	Unconformity.	Unconformity.		Inferred unconformity.	Erosion interval.	Unconformity.	
	Lower Huronian.	Kewatin in part, at least, and Lower Kaministiquia.	Lower Vermilion.	Lower Marquette.	Felch Mountain iron-bearing series.	Menominee proper.	Cherty limestone.	Black River Falls iron-bearing schists (?)	
	Unconformity.	Unconformity?	Unconformity?	Unconformity.	Unconformity.	Unconformity.	Unconformity.	Unconformity?	
Archean.	Marenisean.	(Coutchiching?)	(Coutchiching?)				Southern complex.		
	Eruptive unconformity.	Eruptive unconformity.	Eruptive unconformity.	Fundamental complex.	Fundamental complex.	Fundamental complex.	(Separated in mapping into fine grained schist, Marenisean, and granites and granite-gneisses, Laurentian showing characteristic eruptive contact.)	Fundamental complex.	Minnesota River Valley gneiss and granite.
	Laurentian.	Laurentian.	Laurentian.	(Not yet separated in mapping.)	(Not yet separated in mapping.)	(Not yet separated in mapping.)		(Not yet separated in mapping.)	

the middle portion, and the upper part of the series is free from volcanics.*

Professor Irving divided the Keweenaw into an upper and a lower division. The upper division consists mainly of sandstones, the estimated thickness of which is about 15,000 feet in the middle portion of the Lake Superior basin. On Montreal river the upper division is formed of some 12,000 feet of red sandstone and shale, about 500 feet of black shale alternating with hard, gray, nearly quartzless sandstone, both shale and sandstone being detrital material, and about 1,200 feet of very coarse boulder conglomerate.†

The thickness of the lower division is very great, and may be placed, according to Irving, in round numbers, at from 25,000 to 30,000 feet. On the eastern side of Keweenaw point the maximum thickness of the lower division at surface is some 25,000 feet, which does not go to the base of the series.

The lower division is made up chiefly of a succession of flows of basic rocks. It also includes layers of conglomerate and sandstone nearly to the base, and more or less of original acid rocks. Detrital beds, chiefly porphyry-conglomerates and red sandstones, occur throughout the series, having been seen all the way from the base to the summit, but they are rare in the lower third of the series, and as a rule increase in thickness and frequency toward the top, only one instance being known of a heavy bed at a low horizon.‡

Lower Huronian.—In the Lake Superior region the Lower Huronian is formed of closely folded semi-crystalline rocks consisting of limestones, quartzites, mica-slates, mica-schists, schist-conglomerates, and ferruginous and jaspery beds intersected by basic dikes, and in certain areas by acid eruptives. It includes volcanic clastics, often agglomeratic, and a green, chloritic, finely laminated schist. The thickness of this series has not been worked out with accuracy, but at its maximum it is probably more than 5,000 feet.§

Upper Huronian.—The Keweenaw series rests unconformably on the Upper Huronian. The latter is formed of the Animikie and Upper Vermilion formations in northern Minnesota, and of the Penokee-Gogebic rocks in Michigan and Wisconsin. On Pigeon river, according to Irving, the formations consist of about 10,000 feet of dark gray to black, more or less highly argillaceous or clay-slate-like layers alternating with others that are more quartzitic. Peculiar cherty layers are met with at lower

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* Loc. cit., p. 161.

† Monograph V, U. S. Geol. Survey, 1883, p. 153.

‡ Monograph V, U. S. Geol. Survey, 1883, pp. 152–160.

§ Bull. U. S. Geol. Survey, no. 86, 1892, p. 499.

horizons in the slates, and also banded lean magnetic iron ores similar to those of the Penokee region of Wisconsin. There are also interbedded eruptives, consisting mainly of olivine-gabbros and orthoclase-gabbros.

AGE OF CAMBRIAN BEDS RESTING ON LAKE SUPERIOR SERIES

The fauna of the Cambrian sandstone which comes in contact with the Algonkian rocks in the vicinity of Saint Croix falls is the type of that of the middle Cambrian, and it is probable that by overlap the higher beds of the Cambrian also come in contact with the rocks of the Keweenaw series.

UNCONFORMITY BETWEEN LAKE SUPERIOR SERIES AND CAMBRIAN

A full description of the relations of the Cambrian to the Keweenaw rocks is given by Irving in his monograph on the copper-bearing rocks of lake Superior.* He shows clearly that there is a great unconformity between the two series of strata, and that profound orographic movements and long continued erosion occurred prior to the deposition of the Cambrian rocks (figure 7).

UNCONFORMITIES WITHIN LAKE SUPERIOR SERIES

The unconformities between the Keweenawan and the Upper Huronian, and between the Upper Huronian and the Lower Huronian, and between the Lower Huronian and the Archean have been fully described and discussed by Van Hise,† who states that

> "In the lake Superior region, between the Archean and the Potsdam sandstone, the great Algonkian system is subdivided into three series, which are separated by very considerable unconformities. The lowest series is closely folded, semicrystalline, and consists of limestones, quartzites, mica-slates, mica-schists, schist-conglomerates, and ferruginous and jaspery beds, intersected by basic dikes, and in certain areas also by acid eruptives. It includes volcanic clastics, often agglomeratic, and a green chloritic, finely laminated schist. The thickness of this series has not been worked out with accuracy, but at its maximum it is probably more than 5,000 feet. As the term Huronian has been for many years applied not only to the Upper Huronian series, but to this inferior series about lake Superior, it is called Lower Huronian.
>
> "Above this series is a more gently folded one of conglomerates, quartzites, shales, slates, mica-schists, ferruginous beds, interbedded and cut by greenstones, the whole having a maximum thickness of at least 12,000 feet. In the Animikie district a fossil track has been found, and in the Minnesota quartzites lingula-like forms, as well as an obscure trilobitic-looking impression. Carbonaceous shales are abundant. In its volume, degree of folding, and little-altered character the

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* Mon. U. S. Geol. Survey, vol. v, 1883, p. 366, pl. xxiii.

† Bull. U. S. Geol. Survey, no. 86, 1892, pp. 499–500.

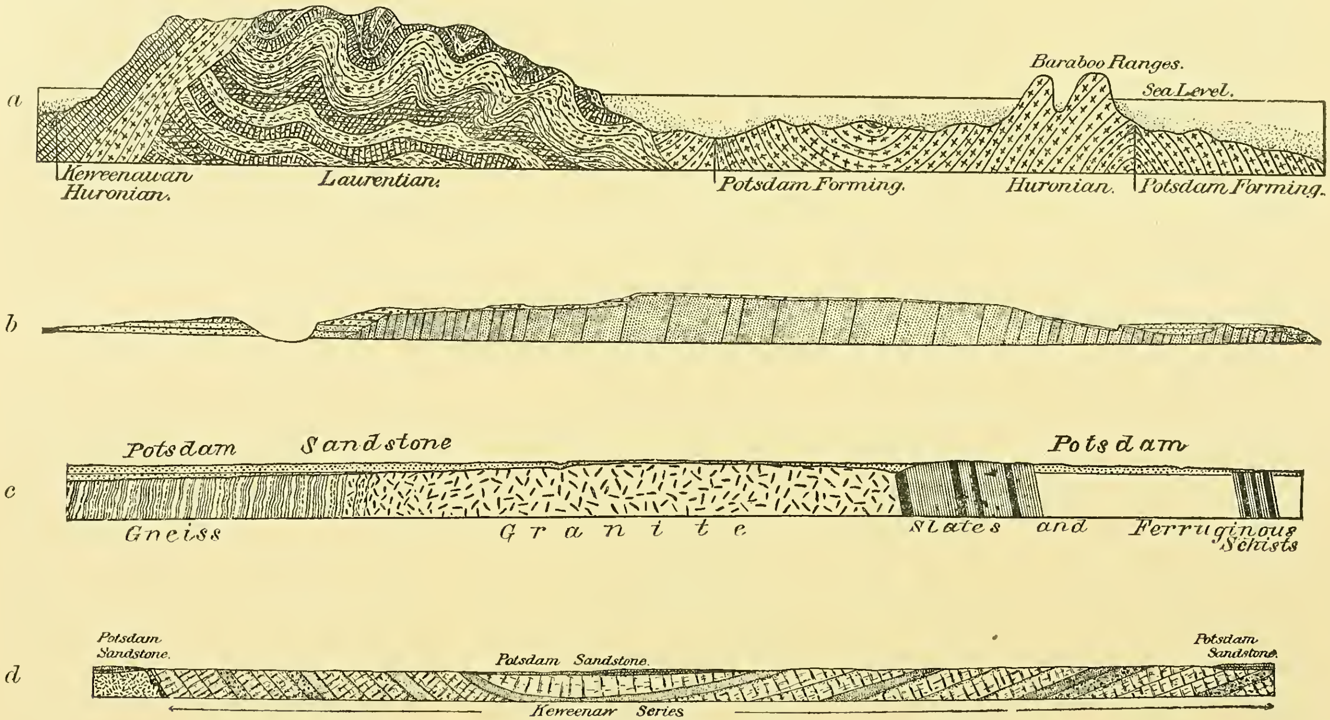

FIGURE 7.—*Sections showing Deposition of Potsdam Sandstone in Wisconsin.*

Upper Huronian is in all respects like the upper series of the original Huronian, and can be correlated with it with a considerable degree of certainty. Above the Upper Huronian is the great Keweenawan series, estimated at its maximum to be 50,000 feet thick, although its average thickness is much less. Its lower division consists largely of basic and acid volcanic flows, but contains thick beds of interstratified sandstones and conglomerates, especially in its upper part. The upper division, 15,000 feet thick, is wholly of detrital material, which is largely derived from the volcanics of the same series.

"The unconformity which separates the Lower Huronian from the Upper Huronian and that which separates the latter from the Keweenawan each represents an interval of time sufficiently long to raise the land above the sea, to fold the rocks, to carry away thousands of feet of sediments, and to depress the land again below the sea—that is, each represents an amount of time which perhaps is as long as any of the periods of deposition themselves. In parts of the region the lowest clastic series rest unconformably on the fundamental complex, but in certain areas the relations have not been ascertained. The upper of the three clastic series, the Keweenawan, rests unconformably below the Cambrian."

PRE-CAMBRIAN SEDIMENTARY ROCKS IN UTAH, NEVADA, CALIFORNIA, AND BRITISH COLUMBIA

Beneath the lowest horizon carrying the Olenellus fauna of the Cordilleran region of the United States and British Columbia there is a great series of silicious slates, sandstones, and occasionally thin bedded limestones in which no trace of life has been discovered. What their relations are to the Belt series of Montana and the Grand Canyon series of Arizona is unknown, as in no locality have they been seen in contact. A somewhat full description of these series is given in Bulletins 81 and 86 of the Geological Survey and in the Tenth Annual Report, pages 549–552.

Whether the fauna that existed at the time of the deposition of the pre-Olenellus beds under consideration has the character of that of the Cambrian is conjectural. It is not improbable that traces of it will be found when the great sections exposed along more than a thousand miles of outcrop are carefully examined by experienced collectors.

Occurrence of Fossils

STRATA OF DETERMINED PRE-CAMBRIAN AGE

An investigation of the reported discovery of fossils in pre-Cambrian formations leaves only three undoubted instances where it can be said that the stratigraphy shows the strata to be of pre-Cambrian age and the traces of fossils are such as to prove their organic origin beyond a reasonable doubt, namely, the Grand Canyon terrane of Arizona, the

DIXON GRAPHITE MINE

Four miles west of Hague, New York

Belt terrane of Montana, and the Etcheminian terrane of New Brunswick and Newfoundland, if the latter proves to be truly pre-Cambrian.

REVIEW OF EVIDENCE CONCERNING FOSSILIFEROUS CHARACTER OF CERTAIN PRE-CAMBRIAN STRATA

Fossils from the Algonkian.—The reported discoveries of fossils in the crystalline rocks of the Algonkian are as yet too problematical to be of value to the geologist and paleontologist. Apparently the best that can be said of Eozoon and allied forms is that they may be of organic origin, but it is not yet proved. The same appears to be true of the supposed fossil sponges described by Mr G. F. Matthew from the Laurentian rocks of New Brunswick,* and the reported occurrence of radiolarians and sponges in the pre-Cambrian rocks of Brittany. The discovery of the latter was announced by Dr Charles Barrois,† and later they were described by Mr L. Cayeux.‡

Dr Hermann Rauff made a critical study of the forms described by Mr Cayeux, and came to the conclusion that they were all of inorganic origin.§

Presence of graphite.—The presence of graphite has frequently been cited as proof of the existence of fucoids in Algonkian time. It is probable that in many cases the graphite is of organic origin, but of the character of the life we know nothing. The finest example known to me of the occurrence of graphite in bedded Algonkian rocks is at the mines 4 miles west of Hague, on lake George, New York. At the mines the alternating layers of graphitic shale or schist form a bed varying from 3 to 13 feet in thickness. The outcrop may be traced for a mile or more. The garnetiferous sandstones form a strong ledge above and below the graphite bed. The appearance is that of a fossil coal-bed, the alteration having changed the coal to graphite and the sandstone to indurated, garnetiferous, almost quartzitic sandstones. The character of the graphite bed is well shown in the accompanying plate (22), from a photograph taken by me in 1890. It is here a little over 6 feet in thickness and is formed of alternating layers of highly graphitic sandy shale and schist.

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* Bull. no. 9, Nat. Hist. Soc. New Brunswick, pp. 42–45.

† Sur la présence de fossiles dans le terrain azoique de Bretagne : Comptes rendus des séances de l'Académie des Sciences, 8 août, 1892, 115, pp. 326–328. Gauthier-Villars et Fils, Quai des Grands-Augustins 55, Paris, 1882.

‡ L. Cayeux : Les preuves de l'existence d'organismes dans les terrains précambriens : Bull. Soc. Géol. France, 3 ser., 22, 1894, pp. 197–228, with two rock profiles and plate 11.

L. Cayeux : Sur la présence de restes de foraminifères dans les terrains précambriens de Bretagne. Comp. rend. Acad. Sci., 118, 1894, pp. 1433–1435, with 6 figures in the text. Ann. Soc. Géol. du Nord, 22, 1894, pp. 116–119, with 6 figures in the text.

L. Cayeux : De l'existence de nombreux débris de Spongiaires dans le Précambrien de Bretagne. Ann. Soc. Géol. du Nord, 23, 1895, pp. 52–65, with plates 1 and 2.

§ Neues Jahrbuch für Mineralogie, etc., 1896, bd. i, pp. 117–138.

Palæotrochis.—Since the first description of Palæotrochis as a coral, by Professor E. Emmons in 1856, it has been frequently referred to as a pre-Paleozoic fossil. At my request Mr J. S. Diller has made a study of the form, and he fully corroborates Professor J. A. Holmes' view that Palæotrochis is of inorganic origin and occurs in an acid volcanic rock. As his notes contain much that is of interest, he kindly prepared the following abstract:

"Professor Ebenezer Emmons in 1856 figured and described * from the 'Taconic' rocks of North Carolina a number of more or less regularly striated, biconical forms, to which he gave the names *Palæotrochis major* and *Palæotrochis minor*, and regarded them not only as silicious corals, but also the oldest representatives of animal life upon the globe. Professor James Hall † regarded them as concretions, and Professor O. C. Marsh ‡ compared them to cone-in-cone. Mr C. H. White, § who strongly advocates the organic nature of Palæotrochis, has published a fuller account of its form and structure.

"Professor J. A. Holmes, State Geologist of North Carolina, in 1887 visited the Sam Christian gold mine and studied the Palæotrochis-bearing rock in the field. He considered the rock of igneous origin, and in this view he has the support of Messrs H. B. C. Nitze and George B. Hanna, who suggest ‖ that the rocks are silicious volcanics, and that at least some of the silicious pebbly concretions are spherulites.

"The specimens which, at the request of Mr Walcott, I had an opportunity to study consist of three fragments about nine inches in diameter, sent by Professor J. A. Holmes, who collected them in 1887 at the Sam Christian gold mine. Besides these, there are from the same place several dozens of the original specimens of Palæotrochis collected by Professor Emmons. Specimens of the rock and isolated fossils have been cut and polished and thin-sections prepared for microscopical study.

"The rock which contains Palæotrochis is full of nodules of various shapes and sizes, ranging from that of a pin's head to nearly two inches in diameter. These are the supposed concretions and fossils, and many of them have a radial fibrous structure which under the influence of the weather becomes white like kaolin. A careful study of the nodules in the hand specimen tends to convince one that however different in form and size they may appear, all belong to one series and have essentially the same origin.

"A microscopical study of thin-sections of the rock reveals the fact that the nodules are spherulites, a common feature in acid volcanic rocks. They are composed in most cases chiefly of fibrous feldspar, with quartz or tridymite. Although the fibers are too fine for optical determination, microscopical tests show them to be feldspar rich in sodium and potassium. The feldspar is probably anorthoclase. The biconical forms which have been called Palæotrochis are generally composed

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* Geological Report of the midland counties of North Carolina, p. 62; also Am. Jour. Sci., 2d ser., vol. xxii, p. 39, and vol. xxiv, p. 151.

† Am. Jour. Sci., 2d ser., vol. xxiii, p. 278.

‡ Ibid., vol. xlv, p. 218.

§ Journal of the Elisha Mitchell Scientific Society, Chapel Hill, North Carolina, part 2, July to December, 1894, pp. 50–66.

‖ North Carolina Geological Survey, Bull. no. 3, pp. 37 and 39.

chiefly of granular quartz, but may often contain also traces of spherulites, and a few of those examined are made up wholly of fibrous feldspathic material—*i. e.*, they are spherulites. In those which are composed of spherulitic matter with granular quartz the latter sends numerous veins of granular quartz into the spherulitic portion, as well as into the surrounding spherulites, and it is evident that the granular quartz was deposited after the development of the spherulites. Recognizing this Palæotrochis rock as a more or less altered ancient volcanic (according to Holmes, pre-Cambrian) full of spherulites, it is easy to understand the great variation in the form, size, and composition of the nodules.

"The Palæotrochis rock is evidently closely related to the acid volcanics studied by Wadsworth * and others in the vicinity of Boston and those of the South mountain, in Pennsylvania and Maryland, described by Dr G. H. Williams † and Miss Bascom.‡

"About a year ago biconical forms like Palæotrochis were presented by Mr Tadatsugu Kochibi, Director of the Geological Survey of Japan, to the United States Geological Survey. These specimens are now in the National Museum, and are much more regular in form, size, and general appearance than the Palæotrochis of North Carolina. They are of a pale pink color, with regular biconical, striated forms, and in some cases have shallow pits in one of the apices. They are known in Japan as 'Soroban ishi,' or abacus stones. One of these specimens contains a small fragment of the rock from which these curious specimens were obtained, and it appears to be spherulitic. According to Mr Willis, who obtained the information directly from Mr Kochibi, 'these stones are found only in rhyolitic tuffs. They not infrequently occur much larger than these specimens, possibly up to two inches in diameter or more, and are more frequently associated in groups of two or three overlapping or coalescing. They are generally white, the rosy tint of these specimens being a rare characteristic.' A thin-section of one of these 'abacus stones' shows it to be an agate of which the outer layers are pink and the inner white. There can be no doubt in this case that the form resulted from the filling of the cavity long after the solidification of the igneous material."

LAKE SUPERIOR SERIES

Fossils have been reported from time to time from the lake Superior pre-Cambrian rocks, but there does not yet appear to be any positive evidence that they have been found in the Keweenaw, the Huronian, or in any of the formations that may be referred to the Algonkian.

In a paper by W. S. Gresley § fossils are described which were found by him in heaps of iron ores upon the docks at Erie, Pennsylvania. The locality was identified on the statement of the dock superintendent that the majority of the specimens came from the Chapin mine, Iron mountain, Menominee range, Michigan.

Professor C. R. Van Hise informs me that in the Menominee district at various points ore is mined from the basal Cambrian, the ore being

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* Bull. of the Museum of Comparative Zoology, Harvard College, vol. v, p. 282, and vol. vii, p. 165.

† Journal of Geology, vol. ii, p. 1, 1894.

‡ Bull. U. S. Geol. Survey, no. 136.

§ Traces of organic remains from the Huronian (?) series at Iron Mountain, Michigan, etc. Trans. Min. Inst. Min. Engineers, 1896, vol. xxvi, p. 527.

largely recomposed from the Huronian deposits. Professor Van Hise thinks that it is not at all certain that the trails and markings described by Gresley were not contained in the sandstone accompanying the ore in the Cambrian formation.

I now have before me the specimens described by Mr Gresley, and it is my judgment that, so far as any of the lithological characters of the matrix can indicate, the specimens were more probably derived from the unaltered Cambrian sandstones than from the more or less altered Huronian sandstone.

In view of this and Professor Van Hise's statement of the occurrence of iron ores in the Menominee district in the Cambrian, I think that we are not warranted in accepting the trails and markings as evidence of life in the pre-Cambrian rocks of the Lake Superior region.

In a paper discussing a supposed fossil from the copper-bearing rocks of lake Superior* Dr M. E. Wadsworth states that in his opinion the specimen is of inorganic origin, probably a "simulative lava flow."

The evidence of life in the Animikie rocks consists of the presence of graphitic material in the slates and of a supposed fossil mentioned by Mr G. F. Matthew. †

Professor Van Hise defines the Upper Huronian as a gently folded series of strata formed of conglomerates, quartzites, shales, slates, mica-schists, ferruginous beds, interbedded and cut by greenstones, the whole having a maximum thickness of at least 12,000 feet. In this series are included the Minnesota and Dakota quartzites. ‡ He mentions the occurrence in the Minnesota quartzites of Lingula-like forms, as well as an obscure trilobitic-looking impression described by Winchell. § The latter I have examined carefully and have concluded that it is of inorganic origin. The Lingula-like forms are so obscure that it is difficult to tell whether they are of organic origin or not. The weight of evidence is in favor of their being small flattened concretions that in some specimens have the appearance of a crushed Obolus or Acrothele.

NEWFOUNDLAND AVALON TERRANE

Fossils.—The Aspidella of the Momable slates of Newfoundland is probably of organic origin, but it may be questioned. It appears to be impracticable to ascertain what the Arenicolite-like fossil is that Mr E. Billings mentions as associated with Aspidella. No specimens are known

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* Proc. Boston Soc. Nat. Hist., vol. xxiii, 1884, p. 208.

† Careful study of the specimen sent to Mr G. F. Matthew by Dr A. R. C. Selwyn leads to the conclusion that the markings attributed to organic agencies are probably of inorganic origin. A photograph of the slab of slate is given on plate xlvi of Monograph xxx, U. S. Geol. Survey.

‡ Bull. U. S. Geol. Survey, no. 86, p. 499.

§ Fossils from the red quartzite at Pipestone. Geol. and Nat. Hist. Survey, Minnesota, Thirteenth Ann. Report for 1884-1885, pp. 65-72. Describes *Lingula calumet* and *Paradoxides barberi.*

to me to be accessible either in the collections of the Geological Survey of Canada or in those of Newfoundland.

Aspidella terranovica, Billings

(Plate 27, figures 7, 8.)

Aspidella terranovica, Billings. Paleozoic Fossils, vol. ii, part i, 1874-1876. Reprint of the Report of the Geological Survey of Newfoundland, 1881, page 286.

> "These are small ovate fossils, five or six lines in length and about one-fourth less in width. They have a narrow, ring-like border, within which there is a concave space all round. In the middle there is a longitudinal, roof-like ridge, from which radiate a number of grooves to the border. The general aspect is that of a small Chiton or Patella flattened by pressure. It is not probable, however, that they are allied to either of these genera.
>
> "Associated with these are numerous specimens of what appear to be *Arenicolites spiralis*, a fossil that occurs in a formation lying below the primordial rocks in Sweden."

Observations.—In the report of the Geological Survey of Newfoundland for 1872 Dr Alexander Murray states that Aspidella is found in division D of the Saint John section or the Momable slates of the Avalon terrane. In addition to the localities mentioned by Billings, Dr Murray found Aspidella in equivalent strata on Trinity bay, at several parts of the valley of the Rocky river, and at Ferryland, where in some cases it literally covers extensive surfaces of the rock in large and small forms, while in other localities single specimens were found scantily distributed.*

Dr A. S. Packard has published a statement to the effect that Mr G. F. Matthew, of Saint John, New Brunswick, doubts the organic character of Aspidella. He quotes him as follows:

> "I have seen *Aspidella terranovica* in the museum at Ottawa and doubt its organic origin. It seems to me a slickensided mud concretion striated by pressure. I have found similar objects in the Etcheminian olive-gray beds below the Saint John group." †

I have not been able to obtain specimens of the Oldhamia mentioned by Dr Murray as occurring near the summit of the slates that I have designated the Torbay slates.

The Etcheminian beds of Newfoundland are referred to under New Brunswick.

NEW BRUNSWICK ETCHEMINIAN TERRANE

The Hanford Brook section shows, according to Mr Matthew,‡ a series

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* Reprint of the Report of the Geological Survey of Newfoundland, 1881, p. 287.

† A half-century of evolution, with special reference to the effects of geological changes on animal life. Proc. Amer. Ass'n Adv. Sci., vol. xlvii, 1898, foot-note, p. 323.

‡ Trans. New York Acad. Sci., vol. xiv, 1895, pp. 107, 108.

of beds (Etcheminian) below the Saint John terrane which contain a fauna that may be pre-Cambrian.* He correlates the "Etcheminian" rocks of the Hanford Brook section with certain red and green sediments on Random sound, Trinity bay, Newfoundland, which occur above the great unconformity between the Avalon terrane and the Cambrian in other localities on the Avalon peninsula.

Mr Matthew writes me, under date of January, 1899, that the evidence of unconformity between the Etcheminian rocks at Random sound and the superjacent Cambrian rocks is that the two series have a different dip, and that the latter have a conglomerate at the base, made up at one locality of fragments of the Etcheminian rocks and at another of fragments of the pre-Etcheminian rocks. He states further that at Hanford brook the non-conformity is not very apparent, but that west and north of Saint John the Etcheminian is entirely eroded and the Saint John Cambrian beds rest directly on the Huronian and Laurentian; further, that the Etcheminian, although separated from the Cambrian, is in near relation to it and the fauna is still Paleozoic.

Mr Matthew has recently written me that he is now preparing a detailed description of the Etcheminian rocks and their contained fossils, which will give the data showing the relations of the Etcheminian fauna to that of the Cambrian.

In a preliminary note he states that the fauna consists of about 20 species.† No traces of trilobites have been found.

> "Various forms of the family Hyolithidæ are the dominant types. Other gasteropods allied to Capulus and Platyceras occur; also brachiopods; remains of echinoderms (cystids?), and corals allied to Archæocythus and Dictyocyathus. The thin limestones which occur in the upper half of the terrane are supposed to have originated chiefly from foraminifera (Globigerina, etc.)"

The supposed fossils described by Mr Matthew from the Laurentian rocks of New Brunswick ‡ are probably of inorganic origin, as stated by Dr Rauff.§

ARIZONA GRAND CANYON SERIES

Fossils.—The traces of life in the Grand Canyon series consist of a few small fossils found in the upper division of the Chuar terrane, and a Stromatopora-like form from the upper portion of the lower division and the central portion of the upper division of the Chuar.

I sent the Stromotapora-like form to Sir William Dawson, who very kindly made a study of it. He was not at all sure that it was a fossil,

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* Loc. cit., p. 109.

† Amer. Geol., vol. xxii, 1898, p. 252.

‡ Bull. no. 9, Nat. Hist. Soc. New Brunswick, pp. 42-45.

§ Neues Jahrbuch Min. Geol. and Pal., 1893, pp. 57-67.

but if so its affinities are nearest to Cryptozoon of Hall. In returning the specimen, in 1883, Sir William sent a note, and later gave the form a specific name.

Cryptozoon ? occidentale, Dawson

(Plate 23, figures 1-4.)

Cryptozoon occidentale, Dawson, 1897. Canadian Record of Science, vol. vii, page 208, figure 3.

A very brief description of the form is given and a microphotograph of a portion of a thin-section. The structure is regarded as possibly corresponding to that of Cryptozoon.

In the note received in 1883 Sir William wrote:

"The specimen presents, both on the weathered surfaces and in slices, a laminated appearance, the laminæ being thin and distant from one another from ½ mm. to 2 mm. They are somewhat unequal in direction as well as unequal in distance.

"The laminæ are composed of silica, and the intervening spaces are filled with granules and bands of silica imbedded in calcite. When the calcite is removed the silica seems to consist of crystalline granules which are so arranged as to give with the calcite a netted appearance, sometimes assuming the aspect of irregular tubular cavities lined with silica. No finer structures are to be observed. If such existed they are probably masked by the crystallization of the silica.

"It would be rash with such material to regard these objects as organic. Something as to this may be based on their mode of recurrence, and possibly new specimens may reveal more distinct structure. So far as the present specimens are concerned, if organic I should suppose them to have been arenaceous tests of some creature allied to that which produced the Ordovician and Cambrian fossils known as Cryptozoon, Hall. These present thin laminæ with the interstices occupied with an arenaceous substance perforated with innumerable curved tubes and chamberlets. The structure on the whole has more resemblance to that of the Carboniferous and Tertiary bodies known as Loftusia, Carpenter. The species *L. columbiana,* described by Dr G. M Dawson, from the Carboniferous rocks of British Columbia, though small in size, more regular and more distinct in structure, is that which most nearly resembles Cryptozoon and also the Grand Canyon species. If really of pre-Cambrian age, it merits more extended and detailed study with the aid of additional specimens, as it may form a connecting link between the Cambrian Cryptozoon and the Laurentian Eozoon.

"I may add that in addition to *C. proliferum* of Hall from the Potsdam of New York and *C. Minnesotense,* Winchell, from the Cambro-Silurian of Minnesota, I have two other forms differing in details of structure. One of these is from the Calciferous of Lachute in the Ottawa district, the other from lake Saint John on the Saguenay, where it was collected by Mr Chambers, of Montreal. I have named them provisionally *C. lachutense* and *C. boreal.** It may further be stated

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*The first of these may be described as in large masses with irregular waving laminæ, sometimes apparently connected by pillars and large interstitial canals or spaces. The second is in elongated lobed masses with laminæ somewhat waving and in groups, the interstitial canals very fine.

that all of these Cryptozoa are apparently more nearly related to the typical *Stromatocerium rugosum* of Hall from the Black River formation than to other Stromatoporoids."

When collecting material in the Chuar terrane in 1883 I was strongly impressed with their resemblance to the forms occurring in the upper Cambrian rocks of Saratoga county, New York, which Professor James Hall subsequently described as *Cryptozoon proliferum.* There were certain differences of occurrence, however, that were noted at the time. These were that the Chuar forms in the Grand canyon were more elevated and were not semi-spherical, as most of the Saratoga forms are. Usually the Chuar forms began at or near the bottom of the layer and gradually expanded upward. If one of the specimens stopped growing or was broken off, one or more began above it and continued on upward to the top of the layers of limestone, or, as in many cases, passed the division line between the two layers of limestone and continued on up toward the summit of the succeeding layer. Where the specimens were very abundant they were from 2 to 3 inches in diameter, whereas where the specimens were scattered they have sometimes reached a diameter of 10 or more inches.

The mode of occurrence strongly suggests the organic origin of the forms named by Dr Dawson and partially illustrated on plate 23 of this paper.

Chuaria circularis, nov. g. and sp.

(Plate 27, figures 12, 13.)

In the sandy, slightly argillaceous shale, 730 feet beneath the summit of the Chuar terrane, a number of circular, disc-like bodies were found, which appear to be the remains of a compressed conical shell. I was at first inclined to regard these as concretions, but, with the discovery of more perfect specimens, this view was abandoned and the objects were referred to as specimens of a small discinoid shell.* The specimens vary in size from 2 to 5 millimeters in diameter. They are concentrically wrinkled, as though a very thin, delicate, almost membranous conical shell had been compressed between the laminæ of the shale. Usually a thin layer of dark bituminous matter covers the surface. When this is removed the shell is smooth and shiny, very much like the glistening surface of a phosphatic shell when slightly dulled by weathering.

The figures illustrating the form exhibit its characteristics, so far as they have been determined.

Formation and locality yielding Chuaria circularis.—Algonkian, Chuar

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* Am. Jour. Sci., vol. xxvi, 1883, p. 195.

terrane, Kwagunt valley, within the Grand canyon of the Colorado, in Arizona.

Some obscure forms.—In the first announcement of the discovery of fossils mention was made of a pteropod allied to *Hyolithes triangularis.* A careful study of the specimens throws so much doubt on this provisional identification that I hesitate to make a positive identification. Had the specimens been found in known Cambrian rocks I should not hesitate to consider them as obscure specimens of Hyolithes. It is possible, however, that they are of mechanical origin (see plate 27, figure 11).

In the gray limestone, about 150 feet above the *Chuaria circularis*, occur what appear to be the obscure remains of a shell which, if seen in the Cambrian, would be referred to the genus Acrothele (plate 27, figure 9). Reference has also been made to a fragment of what appears to have been the pleural lobe of a segment of a trilobite belonging to a genus allied to one of the genera Obolella, Olenoides, or Paridoxides.* It is possible that this is correct, but with the experience gained by a study of the pre-Cambrian fossils of the Belt terrane, I should now hesitate to refer to the fragment as a portion of a trilobite. It is illustrated in plate 27, figure 10.

Dr Carl Wiman illustrates † some small disc-like bodies from the pre-Cambrian shales of the Wisings group, which may or may not be of organic origin. It is interesting to note their resemblance to Chuaria, and the student should read Dr Wiman's description and examine the illustrations when studying the problematical organisms of the pre-Cambrian rocks.

MONTANA BELT TERRANE

Fossils.—The fossils thus far discovered in the Belt terrane occur in the Greyson shales, in a belt of calcareous shales about 100 feet above the Newland limestone, at a horizon approximately 7,700 feet beneath the summit of the Belt terrane at its maximum development. Indications of fossils were first discovered near the mouth of Deep Creek canyon, a short distance above Glenwood postoffice. Subsequently they were found in Sawmill canyon, about 4 miles above Neihart.

The fauna includes 4 species of annelid trails and a variety that appears to have been made by a minute mollusk or crustacean. There also occur in the same shales thousands of fragments of one or more genera of crustaceans. All the specimens are very much compressed and flattened, and often large fragments of the test have been broken by a movement in the shale subsequent to their embedment in the mud.

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* Bull. U. S. Geol. Survey, no. 30, 1886, p. 43, par. 89.

† Bull. Geol. Inst. Upsala, no. 3, vol. ii, 1894.

The most interesting feature of the fauna is the occurrence of undoubted organic remains and the presence of a crustacean of a much higher type than most paleontologists would have predicted for this horizon.

HELMINTHOIDICHNITES, FITCH

Helminthoidichnites ? neihartensis, sp.

(Plate 24, figures 1, 2, 4.)

This is a very narrow trail that may have been made by a slender worm or a minute mollusk or crustacean. From the convolutions shown on the upper portion of figures 2 and 4 (plate 24), the impression is given that the animal moved very much as a small mollusk does when wandering about on the mud at low tide. The numerous small, round, dark spots gathered along the trails and scattered about on the surface of the shale are probably small flattened concretions. They suggest spores of an alga in some specimens (figure 3), but in the great majority of instances they are clearly of concretionary origin.

Formation and localities yielding Helminthoidichnites.—Algonkian, Greyson shales; Deep Creek canyon and Sawmill canyon, Belt mountains, Montana.

Helminthoidichnites ? spiralis, n. sp.

(Plate 24, figures 5, 6.)

These curious spiral trails occur in association with *H. ? neihartensis* in Deep Creek canyon. All that is known of them is shown in the figures.

Helminthoidichnites meeki, n. sp.

(Plate 24, figure 7.)

This is a finely presented trail from the gray fissile shale in which *H. ? spiralis* occurs. It is pressed flat and resembles the smaller specimens of *H. marinus* from the Lower Cambrian slate of Granville, New York.*

PLANOLITES, NICHOLSON

Planolites corrugatus, n. sp.

(Plate 24, figure 8.)

This is the cast of a burrowing worm that shows corrugations or annulations of nearly the same character as those of *Planolites annularius*

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*Tenth Annual Report, U. S. Geol. Survey, 1891, pl. 62.

from the lower Cambrian slates of Greenwich, New York.* It differs little from that species; but it is not probable that the same species of annelid existed at the two distinct geological horizons and on opposite sides of the continent.

Formation and locality yielding Planolites corrugatus.—Algonkian, Greyson shales; Sawmill canyon, 4 miles above Neihart, Montana.

Planolites superbus, n. sp.

(Plate 24, figure 9.)

The cast of a large burrowing worm occurring in a sandy shale interbedded in the *Beltina danai* shales of Sawmill canyon. This burrow indicated the presence of a large annelid that may be compared with some of those that made almost similar burrows in the arenaceous muds of lower Cambrian time and in part throughout geological time from the Belt terrane to the sediments now gathering in seas and lakes. The cast of the burrow extended for some distance in the bed in which it occurred, and several less well preserved specimens were seen near it.

Formation and locality yielding Planolites superbus.—Algonkian, Greyson shales; Sawmill canyon, 4 miles above Neihart, Montana.

Crustacea.—The crustacean remains are in a most unsatisfactory condition of preservation, but they give evidence of the presence of types closely related to the Merostomes that may be represented by more than one genus and several species. I have suspected the presence of a large phyllopod, but have no satisfactory evidence of its presence.

When preparing the note on the "Affinities of the Trilobita," published in 1881,† the class Pœcilopoda was divided into two subclasses, Merostomata and Palæadæ; the former included the orders Xiphosura and Eurypterida, and the subclass Palæadæ including the order Trilobita. Subsequent discoveries have led some naturalists to bring more closely together the Trilobita and the Phyllopoda; but the discovery of representatives of the Merostomata in pre-Cambrian rocks appears to strengthen the view that the Trilobita and the Merostomata are branches of a common line of descent, or that the Trilobita are an offshoot of the main branch represented by the Merostomata. The Phyllopoda and Merostomata may have developed before the Trilobita.

The discussion of this and a number of other questions raised by the presence of such highly organized crustaceans in pre-Cambrian rocks is deferred with the hope that another season's field-work will afford more

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* Tenth Annual Report, U. S. Geol. Survey, 1891, pl. 60, fig. 5.

† Bull. Mus. Comp. Zool., vol. viii, 1881, pp. 208–211.

conclusive information as to the extent and character of this remarkable crustacean fauna.

MEROSTOMATA

Genus *Beltina*, n. g.

Under this generic name it is proposed to place the fragmentary remains of a crustacean, which, as far as can be judged from what we now know of it, is referable to the Merostomata. Thousands of fragments were collected from the calcareous Greyson shales in both Sawmill and Deep Creek canyons. The test appears to have been very thin and without any characteristic surface ornamentation; it is usually preserved in strong relief on the drab-colored slate, and its tenuous character is illustrated by figures 2, 3, and 4 of plate 27, which suggest that it was folded and compressed very much like a piece of paper. To one acquainted with the appearance of the test of Eurypterus and Pterygotus as it occurs in the shaly limestones of central and western New York, there would be no question of the resemblance between the fragments from those beds and the fragments from the Greyson shales of Montana. In each case the test is very thin and is broken into angular fragments, and often is much distorted and compressed.

It is probable that more than one genus, and several species, are included under the genus, but it seems preferable so to include the forms rather than to designate several genera and species on the evidence afforded by the fragmentary material in the collection. Only a few hours were available for collecting material in the field, and it is quite probable that systematic collecting will provide data with which the various forms now placed under Beltina can be classified.

Plate 25, figure 2, illustrates what may be the head of a Eurypterus-like form, and figure 1 suggests the outline of the head of Pterygotus. The telson, figure 18, is the type of that of Pterygotus, as is also the free ramus represented by figures 13 and 14, which was undoubtedly attached to a chelate appendage. The telson represented by figures 4 and 5 of plate 26 suggests the telson of Eurypterus or Stylonurus. The fragments represented by figures 2 and 3 of plate 26 and figure 6 of plate 27 suggest jointed swimming appendages, such as occur in many species of the Merostomata. The appendages which have thus far been found vary greatly in appearance, and in the present state of our information it would be little more than guess-work to attempt to identify them. Such forms as are represented by figures 7, 8, and 9 of plate 25 suggest the basal joint and a slender terminal joint of the cephalic appendages of Eurypterus and Pterygotus. The large appendages indicated by figures 6 and 7 of plate 26 suggest the swimming legs, but they are too imperfect for identification.

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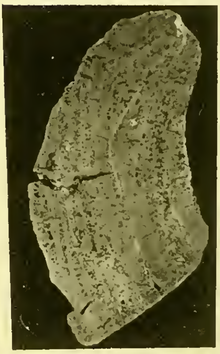

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CRYPTOZOON (?) OCCIDENTALE

If we consider figures 1 and 18 of plate 25 as representing a form which may be compared with Pterygotus, and figure 2 of plate 25 and figures 4 and 5 of plate 26 as Eurypterus, it is possible to consider that the representative of the Merostomata lived in Algonkian time. The evidence is not conclusive, but I am unable to make as satisfactory comparison of the fragmentary remains with any other crustacean. They certainly do not belong to the Trilobita. It may be that they represent the ancestral form from which the Trilobita and the Merostomata were derived.

For the purpose of comparison, some illustrations of recent forms of the Merostomata are given on plate 28. The flattened telson, figure 18 of plate 25, may be compared with figures 2 and 6 of plate 28. A much more extended series of comparisons may be made by examining the illustrations of the Merostomata given by Woodward, Hall, and Schmidt.* It is the purpose of this preliminary notice to call attention only to the fact of the presence of a large, highly organized crustacean in Algonkian rocks far below the horizon at which traces of the Merostomata have hitherto been found, the oldest known being from the Utica shale of central New York.

Beltina danai, n. sp.

(Plates 25, 26, 27.)

The general characters of this species have already been referred to in the remarks under the genus Beltina. The particular form to which the specific name is given is that represented by the Pterygotus-like telson, figure 18 of plate 25, the body segment represented by figure 3, the head represented by figure 1, and the fragments of the chelate appendage represented by figures 13 and 14.

Formation and localities yielding Beltina danai.—Algonkian, Greyson shales; Deep Creek canyon, near Glenwood, and Sawmill canyon, 4 miles above Neihart, Montana.

EXPLANATION OF PLATES

PLATE 23.—*Cryptozoon? occidentale.*

FIGURE 1.—Photograph of a thin-section showing portions of two fragments. Natural size.

FIGURE 2.—Enlargement of the lower, smaller fragment shown in figure 1.

FIGURES 3, 4.—Photographs of two thin-sections occurring in the same stratum of rock as that represented by figure 1.

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* Monograph of British Fossil Crustacea; Paleontology of New York, vol. iii; Mém. Imp. Acad. St. Pétersbourg, seventh series, vol. xxxi.

PLATE 24.—*Annelid Trails on Grayson Shales*

Helminthoidichnites? neihartensis

FIGURE 1.—Two nearly parallel trails, with many small, dark, thin, flattened, usually circular concretions attached to them.

FIGURE 2.—Apparently a single trail made by the animal turning about and finally returning nearly on the line of the first trail. There are not as many concretions as in figure 1.

FIGURE 3.—Enlargement of one of the small disc-like concretions associated with figures 1 and 2.

FIGURE 4.—Same as figures 1 and 2, but with many convolutions. This form is less common than the straight and partially curved trails shown by figures 1 and 2.

Helminthoidichnites? spiralis

FIGURES 5, 6.—Two figures illustrating the typical form of trail made by this curious species.

Helminthoidichnites meekii

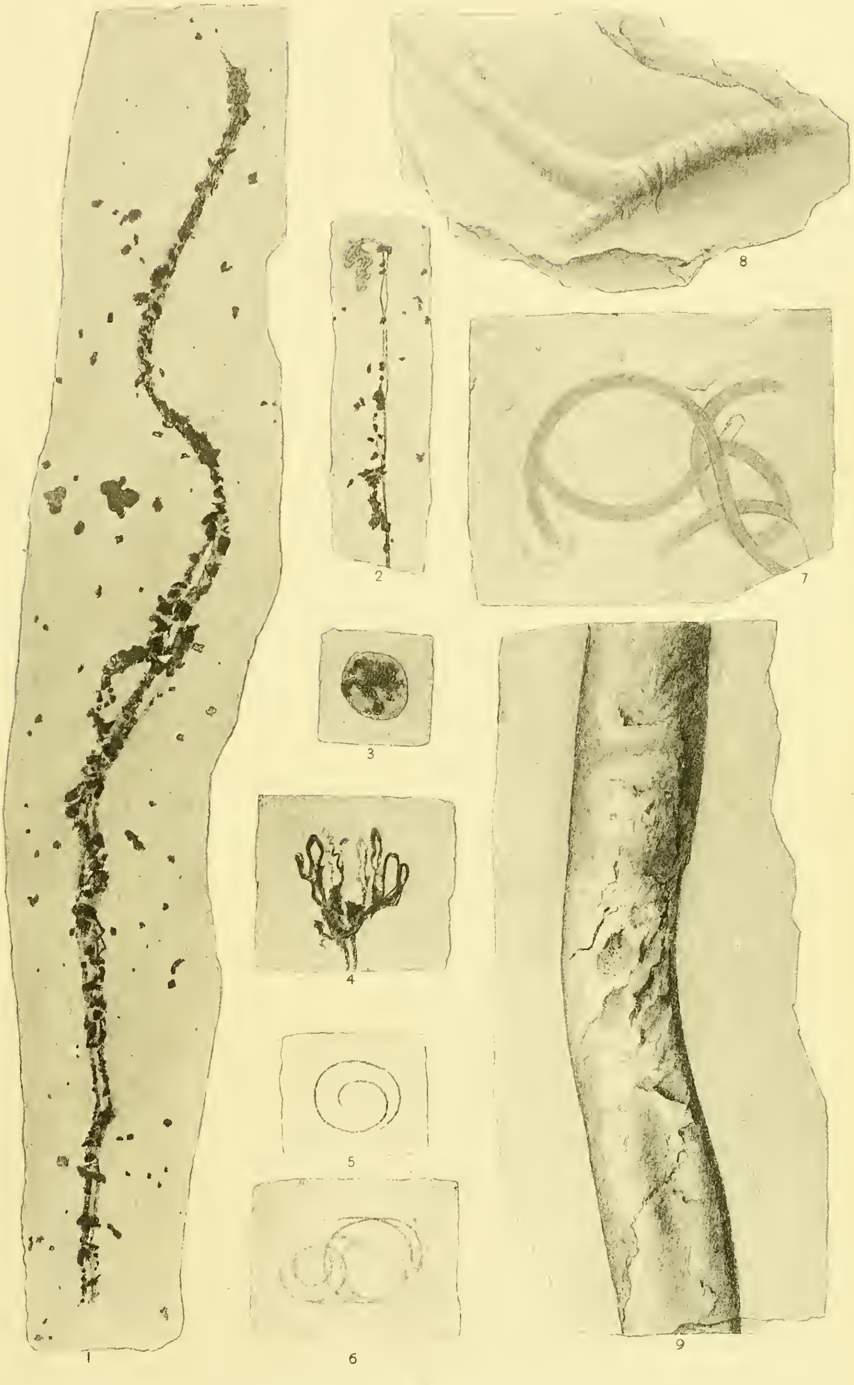
FIGURE 7.—Illustration of the type specimen of the species.

Planolites corrugatus

FIGURE 8.—Exterior cast of the burrow made by medium-size annelid in silicious mud now forming the shales carrying *Beltina danai*.

Planolites superbus

FIGURE 9.—A portion of the cast of a long burrow occurring in a sandy shale interbedded in the *Beltina danai* shales.



ANNELID TRAILS ON GRAYSON SHALES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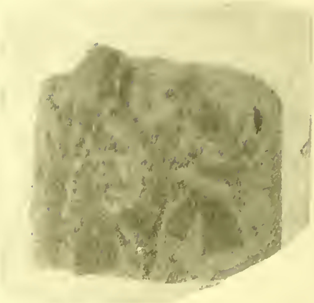
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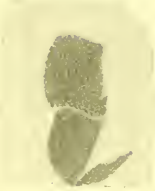
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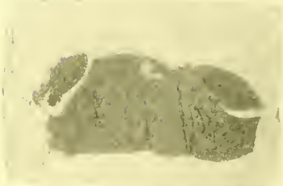
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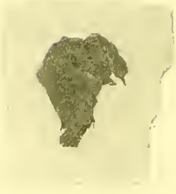
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CRUSTACEAN REMAINS FROM GRAYSON SHALES

PLATE 25.—*Crustacean Remains from Grayson Shales*

Beltina danai

FIGURE 1.—Specimen which appears to represent the head. Figure 2 is greatly compressed and distorted in front and probably belongs to another species. Natural size.

FIGURE 3.—A segment of the body.

FIGURE 4.—Portion of an appendage with four joints indicated. Magnified 3 times.

FIGURE 5.—An unidentified fragment with a small terminal curved spine. Magnified 4 times.

FIGURE 6.—An appendage with two large basal? joints and two smaller terminal joints. Magnified 2 times.

FIGURE 7.—Appendages with a large basal ? joint and four smaller joints indicated. Natural size.

FIGURE 8.—Appendage with very large basal ? joint and several small joints.

FIGURE 9.—Appendage with fragment of large basal ? joint and several small joints.

FIGURE 10.—Two appendages that are apparently attached to a single basal ? joint.

FIGURE 11.—Appendage with a broad basal ? joint.

FIGURE 12.—Appendage with a broad basal ? joint. Several fine setæ or spines are attached to it. Magnified 3 times.

FIGURE 13.—Movable ramus of a chelate appendage, with traces of teeth.

FIGURE 14.—Broken fixed portion of a chelate appendage, with traces of teeth.

FIGURE 15.—Several specimens of this character occur in the collection.

FIGURE 16.—Jointed appendages very much compressed and distorted.

FIGURE 17.—Jointed appendage.

FIGURE 18.—Telson preserving a central ridge.

Plate 26.—*Cretacean Remains from Grayson Shales*

Beltina danai

Figure 1.—Fragment of a large body segment or a portion of the head shield.

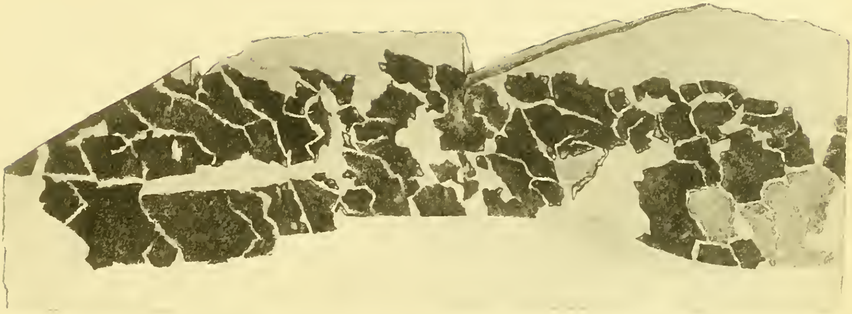
Figures 2, 3.—Probably the broad terminal joints of a swimming appendage.

Figure 4.—Supposed telson of a large Eurypterus-like crustacean.

Figure 5.—Fragment of a telson similar to that represented by figure 4.

Figures 6, 7.—Fragments of supposed large jointed appendages.

Figure 8.—An appendage that is compressed to a thin scale on the shale.



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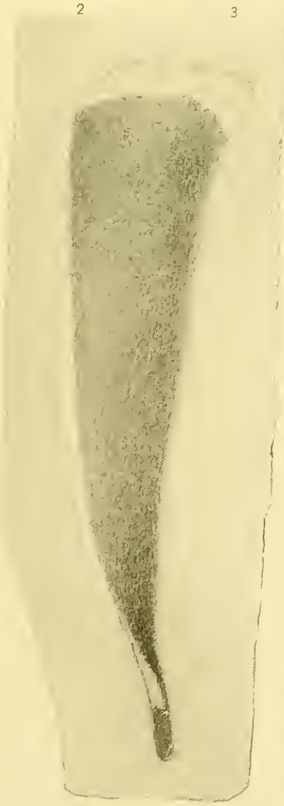

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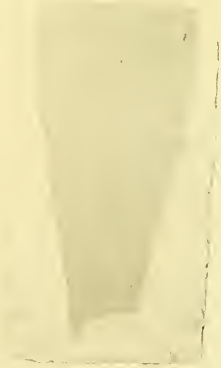

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CRUSTACEAN REMAINS FROM GRAYSON SHALES

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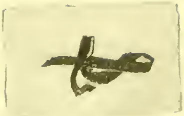

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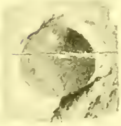

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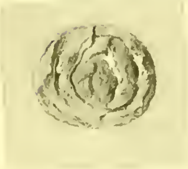

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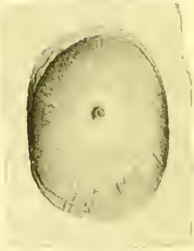

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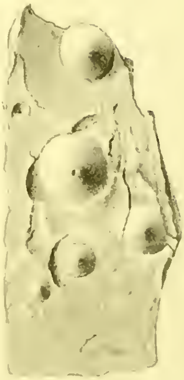

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BELT, AVALON, AND GRAND CANYON TERRANE FOSSILS

Plate 27.—*Belt, Avalon, and Grand Canyon Terrane Fossils*

Eurypterus lanceolatus, Salter

Figure 1.—Photograph after Salter's figure: Monograph of British Fossil Crustacea, order Merostomata, plate 28, figure 2.

Beltina danai

Figures 2, 3, 4.—Fragments of folded and broken test associated with *Beltina danai*. Figure 2 magnified 3 times, figure 4 magnified 3 times.

Figure 5.—Fragment of an appendage.

Figure 6.—Probably the broad terminal joints of a swimming appendage.

Aspidella terranovica

Figures 7, 8.—Type specimens in collection of the Geological Survey of Canada.

Brachiopod?

Figure 9.—Specimen mentioned in the text. Magnified 2 times.

Crustacean?

Figure 10.—Fragment mentioned in the text. Magnified 3 times.

Hyolithes?

Figure 11.—Specimen mentioned in the text.

Chuaria circularis

Figures 12, 13.—Two typical specimens as they occur compressed in the shale. Magnified 6 times.

Aspidella? sp. ?

Figure 14.—A large flattened specimen, showing central apex and obscure radiating lines.

Figure 15.—Group of specimens illustrating variation in size. All appear to be casts of the inner side.

PLATE 28.—*Figures for Comparison*

The figures on this plate are introduced as a means of comparing the fragments illustrated on plates 24 and 25 with known forms of the Merostomata.

Pterygotus anglicus

FIGURE 1.—Restoration of the under side, after Woodward: Monograph of British Fossil Crustacea, order Merostomata, plate 8, figure 2.

FIGURE 2.—Upper side of telson of same.

Eurypterus remipes

FIGURE 3.—Telson and three posterior segments of the body, after Hall: Paleontology of New York, vol. iii, plate 84*a*, figure 1.

FIGURE 4.—Under side of head and anterior body segments, after Hall.

Slimonia acuminata

FIGURE 5.—Upper side of head and anterior body segments, after Woodward: Monograph of British Fossil Crustacea, order Merostomata, plate 20, figure 1.

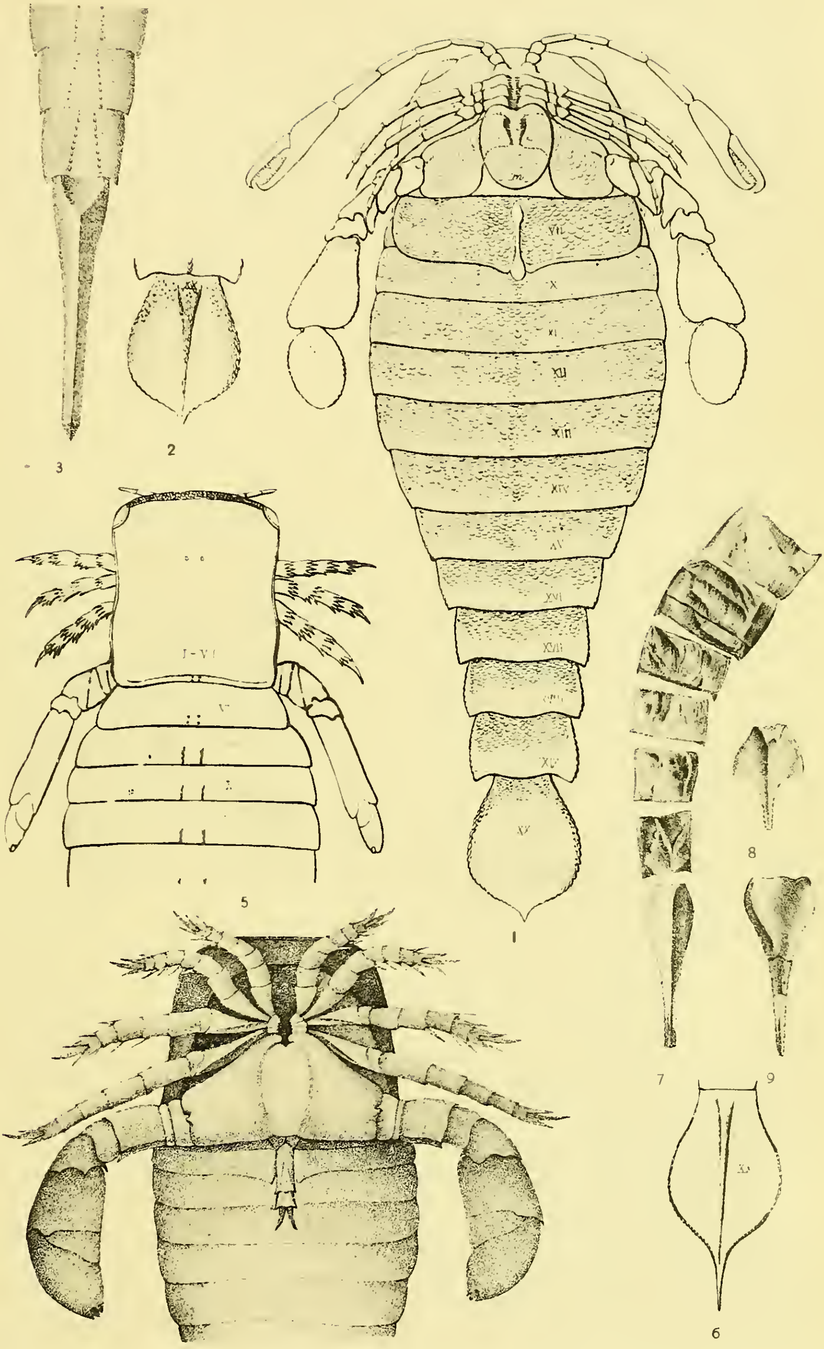
FIGURE 6.—Telson of same.

Stylonurus

FIGURE 7.—Body segments and telson, after Woodward: Monograph of British Fossil Crustacea, order Merostomata, plate 28.

Eurypterus

FIGURES 8, 9.—Telsons referred to Eurypterus by Salter, after Woodward: Monograph of British Fossil Crustacea, order Merostomata, plate 28.



FIGURES FOR COMPARISON

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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LOESS DEPOSITS OF MONTANA

BY N. S. SHALER

(Presented before the Society December 30, 1898)

CONTENTS

FIELDS OF OBSERVATION

In examining certain deposits containing alluvial gold which lie on the upper waters of the Missouri, in the state of Montana, my attention has been called to the occurrence of accumulations of loess now in process of formation. So far as their extent or depth is concerned, these layers of wind-blown material are hardly worthy of remark; but they have a peculiar value as indices of certain alterations of climate which have occurred in relatively recent times, and they are, moreover, agents of change in the regimen of the streams of that district. The facts which are here presented were gathered mainly in the district bordering on the Ruby river, commonly designated on the maps as the Stinking Water, a branch of the Jefferson, on the upper reaches of the Missouri, near Helena, and in the Butte district. Incidentally, notes were made in other parts of Montana and in Utah. The greater portion of the information was obtained in the old placer washings of Alder gulch, a tributary of the Ruby, and on the detrital cone of Alder creek, which lies in the broad valley of that river.

Conditions determining Formation of Loess

The observations which were made justify the general statement that wherever the surface of this prevailingly arid district is moistened by the streams which head in the snow-bearing uplands we find an accumulation of loess which in all cases is somewhat mingled with decayed vegetable matter, the amount of this matter being so variable that the material ranges from a dark loam to an impure soft peat. The thickness of the deposit varies from a few inches to 10 feet or more, being usually greatest in depth where the vegetation covering the surface is richest and where on that account the humus is in largest proportion. Eliminating the organic matter, it will probably be found that the extreme thickness of this deposit, except where it has been washed from its original site and accumulated in low places, does not exceed 6 feet.

The conditions of the formation of this loess deposit may be observed at any time when the earth is dry and the wind strong enough to lift the dust, as is the case for a considerable part of each year. From the surface of the benches of the valleys, as well as from the scantily vegetated lower parts of the mountain ranges, dust is blown to and fro in large quantities. So long as it encounters no closely set vegetation it does not come to rest. It is only when it finds its way amid densely set plants in the limited areas watered by the snow-fed streams that it escapes from the controlling wind. In such places it is quickly fixed to remain so as long as the natural or artificial irrigation continues.

Effects of Loess on Streams

The first consequence of these local accumulations of dust is to be seen in their effect on the course of the streams about which they accumulate. The fine detritus makes a very rich soil, so that a luxuriant vegetation is nurtured. This tangle is likely to obstruct the movements of the water, as the detritus brought down in times of flood lacks the chance of lateral escape which is commonly afforded on detrital cones where loess is not thus deposited. The result is that the bed of the rivulet soon becomes so far raised that it is forced to break a new path, but so long as the water is confined by the dense wall of vegetation on either side it is forced to convey its burden farther out into the valley than would be the case on ordinary barren cones. Probably it is to this action that we may attribute the relatively slight slope of the detrital cones in this arid district, which often have a declivity of no more than 30 or 40 feet to the mile. This small measure of slope is perhaps in part due to the fine silt which they obtain from the loess deposits which are continually forming in the fields adjacent to their beds. Owing to this overburden of sediment, the scouring power of the water becomes very small.

The exceedingly muddy character of the waters of the Missouri may to a great extent be explained by the above noted peculiarity in the delivery of fine silt to its stream. As in other rivers which drain rather arid districts, the torrents and even the main branches of the greater streams are very extensively supplied with wind-blown detritus. In fact, the supply of fine debris thus brought to the streams is much greater than would be afforded them in a humid region, in which there was no wind erosion and where the only seat of its production was the narrow zone of the torrent beds. In this arid district of Montana the delivery of finely divided rock-waste goes on quite as effectively as it does in ordinary humid countries, for the reason that in the time of melting snows and of torrential showers (the so-called cloud-bursts) the torrents are as numerous and for a time as efficient in cutting and carrying pulverized rock as they are in any district I have examined. To this normal silt-making action is here superadded that brought about by the dust which has been swept by the wind to the strip of humid and therefore vegetative ground. In this position the stream, in its normal swingings, is sure, within a limited time, to erode it. In the manner above noted it comes about that a very large part of the finely divided rock matter of this arid district, though not produced in the normal manner by the torrents, is carried through the air to the lower reaches in the broad valleys, and is there held by vegetation until it is taken up by the stream and borne to the main rivers. A portion of this cordilleran dust apparently escapes from the mountain region and is deposited on the plains to the eastward, there also in places mainly adjacent to the rivers, where it is likely to be taken up by their water.

Stratigraphic Relationships and Age of the Loess

The most important geological indications afforded by the loess deposits of the cordilleran valleys are derived from the relation of the beds to those on which they lie. Wherever I have seen this contact it is tolerably sharp. In most instances the underlying material is coarse sand or fine gravel, which rapidly, within 10 feet or less of depth, verges into a pebbly or bouldery bed. These deposits do not contain any distinct trace of wind-blown detritus. The evidence, in a word, goes to show that the passage from conditions of considerably greater rainfall than exists at present to the existing arid state was quickly and recently brought about. This former rainfall gave the torrents much greater transportative force than they have at present, and thus maintained in the region they occupied a coating of vegetation sufficiently dense to prevent the scouring action of the winds. As yet I have not succeeded in finding any satisfactory basis on which to found an estimate of the time which has elapsed since this change occurred, but the impression made upon the observer is that it cannot well exceed a few thousand years. It may possibly have been coincident with the closing stages of the Glacial period, but it appears to have been very much more recent.

In certain parts of central Montana which I have carefully observed, the record of the detrital cones can be traced back from the present day to a time which clearly long antedates the last glacial period. This time is recorded by cemented arkoses, so hard that they have been mistaken by fairly good observers for the ancient schists, and associated thick deposits of volcanic ash, the latter particularly abounding in the valley of Ruby river—ash derived from cones which are now reduced to ruin. At no point in the many sections which I have examined are ancient deposits of loess shown. So far as this negative evidence may be trusted, it indicates that the present arid condition of this part of the cordilleras—that is, the valley of the upper Missouri—is exceptional.

The evidence that the time during which the existing dry condition of central Montana has not been long continued which is afforded by the prevailing thinness of the loess deposits is supported by the indications as to the slight effect which wind erosion has as yet had upon the topographic details of this district. That this form of erosion though now active has not been long continued is clearly indicated by the prevailing sharpness of the water-sculpturing of the lesser reliefs, such as are to be found here and there in the now arid valleys. Thus at a point where Alder gulch opens into the broad and extremely arid valley of Ruby river a detached boss of gneissic rock, rising to the height of 40 or 50 feet above the level of the neighboring valley, in a position where it is much exposed to the action of the blown dust, is very scantily worn. It requires, indeed, close observation to detect any evidence of cutting action such as dust-laden winds effect. Like conditions may be observed at many other points in this and neighboring valleys. So, too, with the pebbles of the mesa-like benches resulting from the erosion of the ancient lacustrine deposits. These fragments are as yet but little worn by the wind-blown sands, and this wearing appears to be limited to the pebbles now exposed—a feature which shows that the surface has not been perceptibly lowered by eolian erosion.

Influences affecting Formation of Loess

VEGETATION

A comparison of the rock surfaces of the vegetated uplands, where no wind erosion occurs, with those of the near-by arid valleys, where this action is at present going on, shows a perceptible though inconsiderable difference in the condition of the exposed rocks in the respective fields. Within the high areas, where the snows hold until late in the spring and gather early in the autumn, the well watered soil is completely bound by the growth of trees and lesser plants, so that it is quite undisturbed by the movements of the air. To this upland realm no dust is borne, except a little of an extremely fine nature. Here we find the rock faces as clearly the work of water or of ice as they are in any part of the Appalachian district. There are, moreover, no traces of loess deposits disclosed along the banks of the streams or in other positions where they would naturally be found. It should also be noticed that, as regards the eolian wearing, the passage from the arid valleys to the verdant high country is, so far as observable, rather gradual, indicating it would appear a progressive advance, in the process of desiccation, up to its present limit. There are no reasons for supposing that there is at present any rapid diminution of the rainfall, if indeed there is any change of this kind in progress.

FIRES

The forests, except where devastated by fires, appear to be holding their lower margins in a fixed position, renewing the growth as the trees die of old age. It is unhappily otherwise where these woods are swept by fire. Where conflagrations destroy the young plants, and even where they do no more than burn the scanty covering of vegetable mould, the edge of the wood is likely to be pushed upward for the height of 500 or 1,000 feet, the area from which the trees are driven being occupied by a growth of lesser plants so scanty that they afford an insufficient protection to the soil. In this way the field open to eolian erosion is being rapidly extended.

IRRIGATION

Some compensation for the increase in the area which is subjected to wind erosion through the action of fire is brought about by the extension of irrigation in the naturally arid valleys. If the fires were prevented this effect would soon be important. As it is, however, the action of the wind is now, year by year, on the increase, and will doubtless be augmented in a rapid manner until this process of devastation is arrested; for with each augmentation in the amount of material in the blast it becomes able more effectively to destroy the lowly plants and thus to obtain a larger share of the soil matter. This fine matter, as before noted, is carried to the margins of the streams, whence it is quickly taken to the sea. Acting in this manner the wind is rapidly taking away from the higher benches of the valleys the at best rather scanty layer of fine detritus which constitutes the true soil, leaving the pebbly waste, so that wide areas which in time might be won to agriculture by irrigation from storage reservoirs are ever becoming less suited to that use.

Remedies for injurious Effects of Loess-forming

This evil can be in part met by an adequate protection of the forests from the fire and by systematic plantation, and also by the introduction from other arid countries of species of plants which are better fitted to thrive in desert conditions. The relatively recent coming of an arid climate to this part of the cordilleras may account for the paucity of species which are adapted to a very dry soil. In other fields where like climatal conditions have endured for a much longer time, as, for instance, in the desert regions of central Asia, we may hope to find plants which can be naturalized here and which will aid in protecting the soil from the wind.

Summary of Conclusions

The foregoing considerations may be summed up as follows:

1. The loess deposits of central Montana indicate that the arid conditions existing in the central section of the cordilleras of North America came about suddenly and have been of no very long duration. In this regard the area probably differs from the districts to the southward.

2. The present arid state followed immediately on a time when the streams were much larger than they are at present; when they were able to build very extensive detrital cones which are now, wherever in their natural state, not receiving additions through the torrent work, but are being sheeted in beneath loess deposits.

3. The essential absence of loess deposits interstratified with gravels indicates that the existing arid period is, as regards modern geological time, quite exceptional, and, furthermore, that since the period when this region was the recipient of extensive showers of volcanic ashes (perhaps the middle Tertiary?) the district has been too humid for the formation of wind-blown deposits.

4. At present the process of desiccation, except so far as it is effected by the burning of the forests, appears to be arrested—a fact which leads to the conclusion that the climatal changes that led to the existing arid conditions are no longer in the process of development.

5. The process of wind erosion here, as elsewhere under like conditions, serves to produce and transport a great amount of fine detritus to the position where it may be readily taken up by the rivers and sent on its way to the sea; the result of this action being at once to increase the efficiency of the river work, to greatly extend the area of effective erosion, and to overburden the streams with fine sediment. Incidentally it serves to diminish the down-cutting of the upper parts of a river system, those just below the true torrents, in which the arid conditions most occur by overloading the water with the transportable material. Thus in an arid mountain region, such as we are considering, there is an upper zone of true torrent work, and below it, occupying more than half of the whole region, a valley zone where the erosion is of a very contrasted nature, being evenly and widely distributed with an aerial delivery of the detritus to the streams.

6. The facts suggest that the total amount of erosion in an arid region where the work of the wind is effective, in a measure found in the existing condition in central Montana, may be much greater than would be the case in a region of far larger rainfall, where the assault on the rocks is practically limited to the torrents; also that the distribution of the erosion in these contrasted climatal states may be very diverse—in the humid aspect of the country greatest in the highlands; in the arid, most effective in the broad lower valleys.

7. The effect of this wind erosion is rapidly to degrade the quality of the soil there by removing the fine material which constitutes the greater part of its value.

It is hardly necessary to suggest the desirability of inquiries having for their aim a determination as to the relative amount of wind erosion in different portions of the cordilleran regions. By means of observations of this kind we may hope in some measure to determine the history of the climate in that part of the continent.

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VOL. 10, PP. 253-262 APRIL 17, 1899

FORMATION OF DIKES AND VEINS

BY N. S. SHALER

(Presented before the Society December 30, 1898)

CONTENTS

INTRODUCTION

Although few writers appear to have concerned themselves, in any careful way, with the question as to the conditions which determine the formation of the fissures in which dikes and veins are deposited, they commonly assume that these seats of the accumulations of igneous or aqueous deposited materials existed before the intrusive matter which has entered the rocks found its resting place. The aim of this paper is to present certain facts and considerations which serve to make the steps by which these structures were formed clearer than they now are. In this inquiry the phenomena of dikes will first be considered; after that, those of veins.

DIKE FISSURES

CLASSES OF DIKES

Even a cursory examination of dike phenomena will show the observer that so far as the fissures which these structures occupy are concerned they are divisible into three groups: Those which clearly follow the planes of preexisting joints, those which are developed along the bedding planes of stratified rocks, and those which more or less deviously burrow their way through the country rock without availing themselves of either of the kinds of incipient cracks which may exist in the rocks they traverse.

MODES OF OCCURRENCE

Not infrequently there may occur in the same field of dike action two of these types of fissures. More rarely all three of them may be found associated within a small area, sometimes in such close juxtaposition that a single hand specimen may exhibit the several types of penetration. It not infrequently occurs that the dike which forces its way upward by developing the joint planes here and there extends laterally through the bedding planes for great distances, and this when the beds are horizontal and the intruding sheets of exceeding tenuity; they may, indeed, not exceed a few millimeters in thickness. Under certain rarely occurring conditions a dike intruded between layers of sedimentation may, as Gilbert has shown, cease to move onward as a sheet of even thickness. When this process of development is arrested before the thrust from below ceases to operate, the relief is accomplished by the process of uplifting the overlying masses forming a local vertical enlargement of the intruded lava in the form well termed "laccolite." Such upward movement of the overlying beds most likely occurs in the intrusion of all the greater sills, though some of them of smaller size may be formed without any uprising of the surface, the space being won through the compression of the rocks, due to the in-wedging action of the dike. This is probably the commonest form of relief in the case of the ordinary vertical or joint-following dikes.

EFFECT OF HEAT ON WALLS

It is noticeable that in nearly all dikes save those of exceptionally great width the effect of the heat of the material on the walls of country rock has been but slight. It is rarely sufficient to produce any fusion of that rock, even where the constitution of the material is such as to favor melting at anything like the temperature which must have existed in the mass of the lava. It is otherwise where the dike has burrowed its way through the deposits it has penetrated without following distinct joints or bed planes. In these instances there is, so far as I have been able to observe, always abundant evidence that the igneous matter has absorbed or fused a large part of the country rock which occupied the position of the intruded mass. This difference in the effect of the dike materials in the rifting and the burrowing dikes—that is, those which follow the planes of distinct beds or joints and those which do not do so—is, as we shall see, a matter of much importance. With these features of dike fissures in mind, let us proceed to consider the conditions under which these fissures are riven.

Influence of Stratification

It is commonly though tacitly assumed that there is some distinct injecting action which drives the liquid rock into the fissures of the solid overlying strata, but I am not aware that any effort has been made to show exactly how such an action is effected. Let us imagine a fluid mass, however developed, lying beneath the deep covering of overlying solid material. Are we to conceive that the dikes are formed as the result of a disruptive action, such as that which rends a bursting shell or steam boiler? Clearly such is not the fact, for in that work the whole of the covering would be rent and the escaping lava would attain the surface. This point is made the clearer by the fact that in the formation of laccolites the overlying strata, which by their extension should give passage for the lava of the congested sill, are not often the seat of numerous upward going dikes leading from the main mass. Even when these overlying rocks are apparently normally jointed, there appears to be some reason why these incipient fractures are not readily opened to the molten rock. It seems, indeed, that in certain cases a section of stratified rock may present conditions which favor the formation of sills extending for great distances in approximately horizontal directions, in directions in which no diminution of pressure is obtained, while a vertical course of the injected materials is to a great extent hindered by the conditions mentioned.

Influence of Jointing

In other instances, the greater number of those in which dikes penetrate stratified rocks, the path of the dike materials is along the joints, a preference being given to those which lie nearest the vertical position.

In these cases, although the bedding planes may be extremely well developed, so that the layers may be separated with the greatest ease, while the joints are very closely adpressed, the intrusions persistently follow the paths of these close fissures, entirely neglecting the opportunity to extend between the beds.

Combination Dikes

In yet other and exceptional occurrences a dike may be formed which has burrowed its way upward without the advantage afforded it by following distinct joint planes, while from point to point it has given off sills which have entered readily between the strata, extending it may be into very thin sheets. Excellent examples of such combinations of dikes, in which great opportunity of vertical extension through layers of rock is combined with exceeding ease in the development of sills, may be observed in the highly metamorphosed slates along the Missouri river, near Helena, Montana, especially in the boulders at the abandoned placers on the banks of that stream.

Causes of Diversity in Dikes

EFFECT OF ROCK STRUCTURE

The wide differences in the behavior of injected lavas when they cover stratified deposits appear to indicate some conditions serving to determine their path other than those afforded by the force which forces them upward or the extent to which the walls of the joint or bedding planes adhere. The facts seem to indicate that in certain cases these joint fissures readily open and give passage to the fluid rock, while in others, in no evident manner different, they resist the entrance of the dike matter in an obstinate way. The question is as to the cause or causes of these variations.

The first suggestion that may be made as to the cause of the diversity which we note in the paths of dikes through stratified rock is that it is due to the relative ease with which the fluid rock forced its way toward the zone of diminished pressure at or near the surface. This view is, however, not reconcilable with observations which may be made in any region where sills abound. It may be there seen how improbable it is that the igneous matter gained in nearness to the surface by extending into the sills.

In certain cases where the beds are tilted the extension along the upward inclined bedding planes may have furnished a way toward the air; but such conditions are rare.

In the greatest number of instances the opening of the space occupied by the sill must have been accomplished by the bodily uplifting of the overlying mass of strata; yet the inducement of lessened pressure could not apparently have been the only action which led to the formation of the far-extending and often relatively very thin sheet of dike matter.

In some examples the sills may be observed to deflect somewhat downward from their original pathway, when the extended overlying beds should have afforded an easier passage by way of the joints.

EFFECT OF WATER

Unable to find any other working hypothesis concerning the development of the paths of dike injections which aids us in understanding the curious conditions of their movements, I have ventured on the conjecture that their course is in part at least determined by the presence or absence of water in the incipient crevices—that is, the joints or bedding planes—or in the relative quantity of that material in those planes. Let us suppose that the molten rock comes in contact with such an incipient fissure containing water, either free or in connection with the rock on either side of the crevice. The effect would be to vaporize this water, or, if the pressure at the given depth were too great to permit vaporization, at least to bring about an expansive strain, which would help to open the space to the entrance of the lava. Should the pressure engendered by this process of vaporizing be less than that which impelled the igneous matter from below, as would doubtless usually be the case, this matter would begin to enter the rent. If the pressure due to the vapor were by chance greater than that impelling the lava it would for the time be debarred from that path. It is perhaps not to be supposed that in ordinary conditions the pressure due to the expansion of water vapor, even in the high temperature which the presence of the fluid rock would occasion, would of itself bring about the opening of the crevice, but this action might cooperate with that of the diking material in determining the course it would follow.

At first sight there appears to be a fundamental difficulty in this hypothesis, in that it does not provide a way by which the vapor of the water generated in the fissure could be disposed of. On consideration, however, it seems eminently probable that relief might be found in either or both of two ways. The stratified rocks would be, it may be assumed, more permeable to vapor than they are to the injected fluid, so that there might be some, though most likely a slow, escape provided in that manner; it is even more likely that the vapor would be absorbed into the molten rock either mechanically or in connection with chemical changes, or these actions, resulting in the removal of the vapor, may be combined.

It must be acknowledged that these processes, though essential to the hypothesis, are somewhat conjectural, but they appear to be in the field of legitimate supposition.

VARIATION IN MOISTURE OF ROCK STRUCTURES

Reviewing the phenomena of dikes in the light of the above noted working hypothesis, we see that they become more intelligible than they now are. Thus, as those who have studied in deep mines have learned, there is a great difference in the extent to which joints and bedding planes contain water. Some are quite dry, others not. It is not unlikely that this difference continues to a much greater depth than our observations extend. The difference is even greater in the case of bedding planes where the water spaces are likely to be more extensive and where the layers of rock may be charged with the fluid. The variations in this feature are obviously great, some sections of strata having the separate members loosely united, while in others they are firmly knit together. Considering these differences, we may conceive that when dike materials seek to force their way upward they may be guided in this movement by the aid which they receive in opening their paths through the action of the expanding vapors. Where the vapors are readily generated in the bedding planes and not in the joints, the lava will be deposited as sills. Where the joints tend to be opened by the steam while there is no like action in the bed planes, no sills will be formed. Where, as is not infrequently the case, the dike has evidently encountered difficulties in breaking its path upward, being forced to make its way without much, if any, assistance from the joint fissures, either because they are not well developed or because they are very tight, we should expect to find, as we do in fact often find, that the sills are well developed. In the case of the dikes of the above-mentioned district near Helena, Montana, this feature of burrowing dikes evidently formed with difficulty, from which extend slender sills, which appear to have been developed with relative ease, is very apparent.

Condition of Sills

So far as my observations extend, the history of diking in every well stratified section shows that when sills are formed they are commonly produced in the first invasions of the igneous rocks, the later injections tending to follow the first planes. This is the order which we should expect if the contact of water with the heated injections was of importance in developing the fissures, for where the layers are so related to one another that there is a storage of water between them, the quantity thus contained is usually much larger than is held in joints; whereas it is usually the case in dikes which follow joint planes that we find one plane or set of planes evidently affording a freer way than others, and the selection of the path may be explained by the fact that the amount of water in different sets of joints varied greatly.

It is to be noted in this connection that in the greater number of dikes the effect of the heated matter on the country rock is, as often remarked, surprisingly small considering the temperatures at which we must suppose the diking matter entered the fissure. If, however, we assume that the fluid rock comes in contact with considerable amounts of water the effect would be to lower its temperature. It is true that so far as this vaporized water afterward combined with the molten rock this effect would be diminished; yet the evidence in general goes to show a lessening of the action of heat, which can best be explained by the supposition that it is taken up in part by the vaporizing process. On the other hand, those dikes of relatively rare occurrence, which have made their way through rocks without following definite rifts, and therefore may be presumed not to have come in contact with other than crevice water, often—indeed we may say quite generally—melt or absorb their walls, as is shown by the absence of parallelism of the walls and also by other evidence.

It can not be assumed that the considerations which have been adduced in the foregoing pages effectively verify the hypothesis above set forth, but they point to the conclusion that further study of the matter may bring about this result.

Vein Fissures

DISSIMILARITY BETWEEN DIKES AND VEINS

Although the early geologists were inclined to regard dikes and veins as species of one genus, it is evident that they have no other common feature than those dependent on the fact that they alike occupy spaces which they have won in rocks in which they did not originally belong.

UNTENABILITY OF THEORY OF OPEN FISSURES

As regards the formation of the fissures in which veins are contained—the point with which we are here concerned—the original view was to the effect that these rents were freely open at the time when the deposits were laid on their walls. This view has been generally abandoned—at least, in its unqualified form—though it is perpetuated in many of our text books. The evidence concerning the formation of vein fissures goes to show that only rarely could veins have been deposited in widely open fissures; such rents have occasionally been observed in mines at considerable depth beneath the surface, but within the zone where the greater part of the vein building takes place we may fairly presume that the pressure is such as would prevent the development of freely open crevices. Such, indeed, could not be maintained at the depth of even 3 miles below the surface, except they were filled with water which had no chance to escape upwardly as fluid or vapor. The only kind of fissure which could, except for the presence of water, be maintained at any great depth would be such as were formed by faults, the walls of which were not perfectly parallel—a condition of all faults—so that when slipped apart one from another, though closely adpressed, a winding cavity would be formed by the contact of the warped surfaces; but it is doubtful if even such openings could be maintained at the depths where most veins are deposited. The well known fact that veins usually contain here and there masses of the country rock which have been forced out of position laterally by the formation of the vein matter, but have not fallen downward, and that in no case within my observation has a mass of the country rock disappeared in a way to suggest such downfalling, shows pretty clearly that the deposition in wide veins rarely if ever occurs in previously open fissures; that is, those in which there is a cavity having an area anything like that occupied by the completed vein. It therefore becomes a question as to the mode in which the vein material finds its way to the place of deposition.

ILLUSTRATION OF VEIN-FORMING FROM GEODES

Some light on the foregoing question appears to be afforded by observations which may be readily made on the formation of geodes. As is well known, these bodies in their typical form are spheroidal masses, usually of quartz, which are formed essentially in the manner of veins. They may, indeed, be termed globular deposits in this class; in fact, by extending the inquiry over a large field I have been able to trace a tolerably complete series of forms from spherical geodes to ordinary fissure veins, a series sufficiently without breaks to warrant the assumption that all these bodies belong in one category. A study of these geodes as they occur in Kentucky and elsewhere, especially in the shales of the sub-Carboniferous rock, has afforded me some interesting and instructive suggestions concerning the process of vein-making which I will now briefly set forth.

Normal geodes are hollow spheroids and are generally found in shales. They clearly represent in most cases a segregation of silica, which has evidently taken place under conditions of no very great heat, brought about by deep burial beneath sediments or other sources of temperature. It is difficult in all cases to observe the circumstances of their origin, but in certain instructive instances this can be traced. It is there as follows: Where in a bed in which the conditions have permitted the formation of geodes the calyx of a crinoid occurs, the planes of junction of the several plates of which it is composed may become the seat of vein-building. As the process advances these plates are pushed apart and in course of time enwrapped by the silica until the original sphere may attain many times its original diameter and all trace of its origin lost to view, though it may be more or less clearly revealed by breaking the mass.

In the process of enlargement which the geodes undergo they evidently provide the space for their storage by compressing the rock in which they are formed. In the rare instances where I have been able clearly to observe them in their original position they were evidently cramped against the country rock, the layers of which they had condensed and more or less deformed. Although when found upon the talus slopes or the soil these spheres usually contain no water in their central cavities, these spaces are filled with the fluid while they are forming and so long as they are deeply buried. There can be no doubt that this water is under a considerable though variable pressure.

The conditions of formation of spheroidal veins or geodes clearly indicate that an apparently solid mass of crystalline structure may be in effect easily permeated by vein-building waters, and this when the temperatures and pressures could not have been great. It is readily seen that the walls of these hollow spheres grow interstitially while at the same time the crystals projecting from the inner side of the shell grow toward the center. We therefore have to recognize the fact that the silex-bearing water penetrated through the dense wall. In many of these spherical veins we may note that the process of growth in the interior of the spheres has been from time to time interrupted and again resumed. These changes may be due to the variations in pressure to which the water in the cavities is necessarily subjected as the conditions of its passage through the geode-bearing zone are altered.

The most important information we obtain from the study of spherical veins or geodes is that no distinct fissures or rifts are required for the passage of vein-building waters through existing masses of lodes. It is true that the distances they traverse in these spherical lodes is limited to, at most, a few inches; but there is in these cases no other impulse than diffusive action to bring about the movement, while in an ordinary tabulate vein we may generally assume, in addition to the influence operating in bringing the dissolved materials into the geode, a pressure which impels the fluid upward. Thus, while it is not to be denied that many veins are prepared for by the formation of somewhat gaping fissures, and that these rents, after being more or less completely closed, are reopened by faulting on the plane of the deposit, such original or secondary spaces are not required for the development of a vein. The other point is that the pressure of the growing vein, which in the case of the geode is able so to condense the rock matter about it as to win room for the deposit, is likely to be even more effective in the group of tabulate deposits in forcing the walls asunder.

Condensing and Deforming Effects of Vein and Dike Materials

In this connection it may be well to note that the introduction of large amounts of vein and dike material brought from lower to higher levels of the rocks is likely to prove an important source of condensation and deformation of the beds in which the deposits are formed. I have elsewhere referred in some detail to the importance of this action. It clearly deserves more attention than it has yet received.

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SPACING OF RIVERS WITH REFERENCE TO HYPOTHESIS OF BASELEVELING

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(*Presented before the Society December 30, 1898*)

CONTENTS

METHOD OF STUDY

AUTHOR'S FIRST OBSERVATIONS

A glance at any accurate maps will show that water-courses in nearly all regions are so disposed that they are somewhat regularly spaced, the intervals between their channels of like size being approximately the same even when the character of the rocks and the amount of the rainfall are somewhat varied. My attention was called to this fact some 20 years ago, when considering the relations of the rivers of Kentucky. While comparing the order of the under and over ground channels of that district I noted that while the cavern waters followed no distinct order in their placement, except such as was determined by the jointing of the limestone rocks in which they were excavated, the surface streams of the neighboring cavernless country were grouped with rather definite intervals which did not distinctly vary, whatever the character of the subjacent rock might be. A debate which occurred in the geological conference of Harvard University in 1897, on a paper presented by Professor Penck, of Vienna, showed me that this distinguished geographer had noted like facts in the Alps and in the Cordilleras, and indeed it must have attracted the attention of many observers. This revival of the inquiry has led me to the observations and inferences which are set forth below.

EVIDENCE FURNISHED BY TOPOGRAPHIC MAPS

First, let us note in a more detailed way the certain important facts concerning the placement of streams which has just been stated as a very general proposition. Taking a series of maps which show in an accurate manner the geological and topographical aspects of diversely conditioned areas, we may readily observe that on those areas which have been long and continuously exposed to the effective work of streams the spacing of the channels is in the greatest measure uniform. On the other hand, where, as in the coastal plain districts of the United States, the surface has recently risen from the sea, the intervals between the streams of all sizes is much more irregular. Again, in countries of inconsiderable reliefs which have had their former drainage system effaced by a deep coating of glacial drift the order of position of the newly determined channels has something like the irregularity which is exhibited by newly elevated area. The fact that the likeness and the order of streams is least evident where they have acted for the shortest time, and most so where they have been long in operation, suggests the hypothesis that the distribution of their channels in an equable manner is in some way brought about by the action of the streams themselves; that in wearing downward they work in a manner which tends to equalize their intervals.

VALUE OF STUDYING BEGINNINGS OF STREAM WORK

Apparently the best method of approaching the discussion of the view just stated is by observing what takes place in those beginnings of stream-work which we may observe wherever a sloping surface of earth has been exposed to the action of the rain. On such surfaces, as is well known, a drainage system in miniature is quickly developed, the channels at the beginnings of the process being very small and much branched, and the whole appearing, as has often been remarked, like a reduced model of a river system. By tracing the successive changes of these small temporary channels we may acquire much information as to what goes on in the slower but otherwise approximately similar process which takes place as the larger streams work downward into the rocks they traverse.

CONDITIONS OF SMALL STREAMS

EXPERIMENTS WITH THIN LAYERS OF WATER

First, let us observe the conditions of the thin layer of water as it moves over a slightly tilted uniform surface such as a plate of glass. As the water is impelled by gravity to flow it shows an interesting tendency to gather into streams rather than to move as a sheet. Even the slight irregularities of the nearly perfect plane tends to create definite streamings. If now a thin coating of any fine somewhat adhesive material be placed on the plate, for instance, such as close grained clay, we note at once a distinct tendency to channeling—a drainage is in fact at once organized, the troughs of which will be rapidly deepened until the conditions of the rain-washed fields are essentially reproduced. It is thus made evident that the circumstances of movement of the thin layer of water which the rain brings to the sloping surfaces of the earth are such that very slight irregularities inevitably bring about the formation of distinct streams. If the earth were in a state to feel the effect of these tiny currents, it would, save in the very arid districts, be carved by channels so small that several would be traceable in each square foot. That such is not the case is due to the fact that almost everywhere the coating of vegetation is sufficiently dense to protect the soil from all except the considerable rivulets. It is only where a very great number of small temporary streams have combined to form a torrent that the energy of the moving water is sufficient to cut through the matted vegetation and to attack the soil.

INFLUENCE OF VEGETATION

While the existence of a vegetable coating in the natural field and its absence in the bared areas we are now considering is a noteworthy difference, one in certain ways affecting the value of the experiments, it does not really invalidate them. The effect of the plants is to limit the cutting action to much fewer streams—those, as above remarked, where the aggregated waters are able to brush away the mantle of vegetation. It thus comes about that there is commonly a broad field between the headwaters of adjacent rivers, which is protected from mechanical erosion by the fact that the lesser brooks can not attack the subjacent earth. In this way the formation of tablelands is favored, the destruction of the level areas being effected mainly by solutional processes until the retreating head escarpments of the larger streams work back across the surface of the upland. Notwithstanding these differences between the small and the great erosive work, the exhibitions of it which are afforded in the miniature stream systems throw much light upon true river action.

EFFECT OF RAIN ON SMOOTH, SLOPING SURFACES

In the first stage of rain work on a moderately smooth and gently sloping surface of bared earth we find the very numerous closely set little valleys before noted, such as may be produced in the course of half an hour of moderate rainfall. If we watch the further steps of the process we observe that as these channels cut deeper the valleys of some of them are widened, so that in an area where there was at first a dozen distinct grooves there is now perhaps but one. A change of this sort may at times be traced in the course of a few hours of continuous rain. It is, however, better seen during a season's changes which deepens valleys from the average depth of half an inch to that of a foot or more, with proportionate reduction in the number per unit of area.

Inspection of the process of change in the swiftly developing valleys of bared earth at once shows that the increase in the size of the channel is brought about by a process in which certain of the streams cut down and laterally with greater rapidity than the others. This process of development is in its nature and methods one of selection; it more clearly resembles the principle of the survival of the fittest than any other known to me in the inorganic realm. The reason for this likeness is to be found in the fact that in the mechanical changes of the streamlet, as in those of the living form, success is determined by the adjustment of the action to exceedingly varied conditions. In each we have something like a continuity of endeavor with the limitation which circumstances put upon it. In the institution of a very small drainage system, such as we are considering, the first action is determined by the currents which set up in the sheet of water before it begins to cut. The initial channels are in effect a map of these original streams. As soon as scouring begins those guiding features arising from the diversities of the surface and of the initial cutting power of the streams at once gives some of them the mastery. To perceive the value of these differences we should note that the cutting power of the currents increases in a very high ratio to their speed, certainly as the square thereof, and perhaps in a much higher function. The result is that, given a very slight preponderance in size of one stream among many, this advantage will cause its channel to cut down more rapidly than do those of its competitors. As it extends its drainage slopes from its rapidly lowered base it inevitably captures the valleys from its smaller neighbors. This process, with minor variations in the method of work, goes on until the divides of the valley are forced back to a point where they encounter those of another stream which is doing similarly effective work.

DRAINAGE DEVELOPMENT AND ITS APPLICATION TO STUDY OF RIVER SPACING

In the advancing stages of drainage development in the natural model we are considering we find the process of lateral appropriation of the smaller channels is brought about in at least three ways: (*a*) As the channel is deepened the side slopes of the valley keep their original angle of declivity, and thus invade the basins on either side; these, by reason of the reduction of the drainage thereby brought about, work downward with less rapidity. (*b*) The lateral shifting of the streams as they are blockaded by the less movable waste also causes them here and there to invade the drainage of their neighbors. (*c*) Lastly, the peculiar process termed "piracy" occurs—that is, the small branches of the larger main stream work back through the divides until they tap and divert the adjacent higher lying water-courses. In a word, all the methods by which an ordinary river extends its field of drainage are fairly well represented in the miniature stream system.

If with these observations in mind the student proceeds to inquire concerning the difficult question as to the equal spacing of river channels of like size, he will find the explanation he seeks. He will note that the slopes of the drainage basins are, as regards their angles of declivity, quite as uniform as are their spacings; all of them meet in sharp crests, the divides between several valleys. These crests, as well as the lowlands, are wasting; but while the streams cut down freely, the crest lines descend at a slower rate. As long as the streams on either side of the divide work their beds downward with equal rapidity the ridge maintains its position; but if one descends more slowly than the other, then, as the slopes of their valleys are uniform, the deeper lying river pushes the crest back, thereby capturing a part of the watershed of its neighbor, with the result that the diminished valley will be less rapidly worn down than before, and therefore the more easily destroyed by the vigorous contestant. In this way it comes about that the lesser velleys are apt to be ruined by the development of the greater adjacent excavations. There is, however, as before noted, a limit to this action, which is set by the fixed angle of the side slopes of the valleys. This is determined by the character of the material which is wearing away. In the miniature example this wearing is purely erosive, and is commonly rather even in rate, for the reason that the soil is likely to be of a uniform composition. It is different in the case of ordinary river valleys, but the difference does not affect the principle involved, which is that the effective angle of the side slopes of the basin goes far to determine the limits of its lateral extension.

CONDITIONS OF TORRENTS

RELATION OF SLOPE TO DOWN-CUTTING AND BASIN AREA

With the principle last noted, that the declivity of a basin's slopes determines the range of its capturing, in mind, seeing also that the relative rate of down-cutting of the channel established the condition of the stream as winning or losing in drainage area, let us further consider the conditions which determine this down-cutting. In the first stages of the excavating work the miniature stream cuts very freely, the restraints of its baselevel not being felt. In a word, it is a torrent. As its bed grows deeper this influence begins to come in. The result is that the stream soon passes the stage in which it is gaining in volume by capturing drainage. Such augmentation as it receives in the later stages of down-cutting are not likely to add much to its drainage area. Bearing in mind the fact concerning this loss of power, namely, that the speed is about as the square of the declivity and the efficient carrying energy as a higher function of the speed, we may readily perceive that a very sudden arrest is put to the capacity of the current to cut its bed deeper when it attains a certain diminution of slope.

It should now be possible to see why the rivulets on a considerably eroded surface of an originally even slope, however irregular they may be at the beginning, come to be rather evenly spaced in the course of their development. This spacing is in effect determined by the maximum depth to which the beds of the streams can cut down in a given time. Those channels which attain that depth do so because they manage to carry their load of debris beyond the field. If the waste is fed in too rapidly the cutting down is hindered. If they cut down to a certain grade they attain a critical point due to the diminished slope, beyond which they can not well become deeper. The result of these several equations of action is the establishment of a somewhat definite maximum area of basin, beyond the limits of which a stream can not effectively compete with its neighbors.

The conditions which make for the establishment of approximately equal intervals between the drainage channels may be fairly well illustrated by pressing down V-shaped blocks of equal size into a sheet of mud so as to make valleys of like dimensions. Imagine, now, that there is an arrest of the down-sinking of any valley as it comes to a certain critical plane the equivalent of the baselevel of erosion, and that the side slopes of the trough have the same declivity; it should at the same time be borne in mind that wherever a stream fails to work downward as rapidly as that of the adjacent channels, its drainage is invaded by the extension of the side slopes of its competitors, with the result that it still further loses its capacity to hold its original down-cutting power, its area being soon shared in something like equal measure by the more successful streams. The further this process continues the more complete the work of effacing the original irregularities of interval.

APPLICATION OF EXPERIMENTS AND OBSERVATIONS TO STUDY OF NATURAL CONDITIONS

If from these observations on the convenient miniature specimens, showing the conditions under which drainage channels are established and developed, we turn to the larger examples of such work, as are exhibited in river systems, we note at once the advantage of approaching our problem in the manner which has been pursued. In the first place, we see that the equality of the spacings in the larger streams is most perfect in those which in size and character nearly approach the small temporary gullies of newly bared soil. The torrent gorges which are cut in uniformly yielding rock are often as accurately spaced as in the smaller samples, though they may have the depth of hundreds of feet and an average width of a mile or more. As we pass to the true rivers the symmetry becomes less and less perfect as they increase in size. It may be said that in proportion as the grade of the side slopes leading to the divide diminishes and becomes thereby less regular, the spacing becomes less even.

The reason for the less regular intervals between the valleys of gentle declivity and moderate side slopes and those of rapid fall with steep slopes are numerous. Among them we may note the following: As the stream approaches its baselevel it is proportionately more and more affected by various influences which tend to deflect it from the center of its valley. Obstacles which should have been disregarded or easily overcome while the descent was steep now control its movement. This causes the lateral extension of the valley to be forced this way or that; it no longer, as before, induces the attack on the adjacent slopes to be tolerably uniform. In the basins of gentle descent the nature of the underlying rock is likely to play a more important part in controlling the topography and the share of solutional action greater than is the case in the torrential valleys. It is also to be noted that in districts which are underlaid by limestones, except they be dolomites, where the position of streams may be fixed by the formation of underground water-courses, which in the course of time become open channels, the arrangement of the streams is often extremely irregular. In such case their order is determined by the jointing of the rocks and other details of structure and attitude which do not have controlling influence on surface rivers.

The foregoing considerations concerning the spacing of rivers, though in themselves matters of interest, as they point the way to a clear understanding of important geological problems, have a much wider application than appears at first sight. I shall now endeavor to show that they may bear on the question as to the origin of the coincidences in mountain crests, which is so generally held to indicate the existence of ancient baselevels of erosion which have been lifted to a hight above the level of the sea and then dissected by rivers. To perceive the value of these indications we must again revert to the facts shown in the miniature valley. It is noticeable that the divides between these streams are often maintained in about the same plane to whatever depth the general surface may be lowered. I have seen instances of it where the valleys had cut down to a depth greater than their width. This element of regularity is quite as evident as the uniformity of spacing between the channels. The crests, of course, rise toward the headwaters of the basins which they separate, but where a considerable field is incised in this manner the nodal points of the drainage remain approximately at the same hight above the baselevel.

Bearing of Evidence on Baseleveling

RELATION OF DOWN-WEARING TO UNIFORMITY OF LEVEL

At first sight it may seem that this identity of attitude of the remaining highlands in the system of miniature valleys is due to the original equality of the surface on which the work of erosion began. Observations show, however, that even where there is a great variety in elevation the process of down-wearing tends to bring the varied levels into uniformity. In the small scale, rapidly forming drainage this action is more easily recognized than it is in the case of true river basins. The process may indeed be seen in actual operation. Where there are considerable elevations their slopes are steeper and erosive work goes on upon them much more speedily than elsewhere, until their declivities are brought down to the uniform grade of the slopes which the material takes with a given measure of rainfall. The important point is to discern that an approach to uniformity of interval and lateral slopes of valleys effectively tends to bring about a likeness in the hight of the divides even where the original surface was of varied elevation.

BASELEVELS OF THE APPALACHIANS

To apply this principle to the matter of ancient baselevels, let us take what is a most characteristic instance, that of the Appalachians. As regards this region a common hight of summits over large areas has been explained by the supposition that at one or more stages in the history of the area the mountain-built rocks have been worn down to or near their baselevel of erosion, subsequently elevated, and thereafter subjected to the stream erosion which has carved out the existing reliefs.* Considering first the general character of this field as regards the hight of its elevation, we note that, despite the variations in the resistance to erosion, there are sundry parts of it in which the elevation of the highest ridges and peaks are tolerably uniform, so much so indeed as to make the supposition of an ancient baselevel a good working hypothesis. Thus in the hills of Nova Scotia, in the Green mountains and their southern extensions in the Berkshire hills, and in the Alleghanies as far as Alabama we find accordant hights which at first sight appear to be readily explained by the supposition that the erosive work began after the areas had been brought to near the baselevel and afterward uplifted to a hight not far above that which the existing crests attain. For the purpose of our inquiry it will be well to begin with the Alleghanian district, taking account of the areas to the east, including the Blue Ridge mountains and the Piedmont area. More than any other known to me, this field of the southern Appalachians affords good data for discussing the problem in hand.

The features of the area above designated which first claim attention in the inquiry are, first, the tolerably accordant levels of the Alleghany section with hight, which in a general way decline from near Cumberland gap to the plain of southern Alabama; next the presence of a great valley or system of valleys on the western side of the Blue Ridge; then the rise to the southward of the Blue Ridge in the Smoky mountains, and, lastly, the uniform eastward sloping plateau of the Piedmont area, composed of highly metamorphic mountain-built rock, presumably of Cambrian or of Archean, but containing many areas of Mesozoic folded strata. These three mountainous elements of the Appalachians I have for convenience termed the western, the central, and the eastern divisions of that great system. The central is the oldest in the order of formation, owing its existence in part to orogenic actions which probably occurred before the beginning of the Cambrian age. The western or Alleghanian was dislocated nearly at the close of Paleozoic time. The eastern or Piedmont was in large part mountain-built after the close of the Jurassic period, though it doubtless shared with the Blue Ridge mountains in the much earlier disturbance to which it owes its structure.

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* For admirable presentations of this view see Arthur Keith: Geology of the Catoctin Belt, 14th Ann. Rep. U. S. Geological Survey, p. 293 et seq.; also, Hayes (Willard) and Campbell (Marius R.): Geomorphology of the Southern Appalachians, National Geographic Mag., vol. vi, p. 63 et seq.

For this inquiry the most important contrast in the fields above mentioned is in the measure of their degradation, their hight above the sea, and the form of their reliefs. Considered in a general way, it is evident that the Green Mountain district, embodying the Berkshire hills and the Alleghanies, may be, as regards their altitude, not unreasonably grouped together, their hights being in the whole similar, the peaks which surpass an altitude of about 2,000 feet being rather exceptional, and perhaps explainable on the theory that they are due to local resistance to downwearing action. So, too, the Piedmont area, where the slope rises from tidewater westward to the level of about 1,000 feet, exhibits much uniformity in the hight of the crests at equal distances from the central Appalachians, but with many " monadnocks " or steep, isolated peaks rising far above the general plane of crest altitude. In the central section there is, in my opinion, no such accordance in the hights that point to baseleveling followed by elevation, the range in elevation being from about 1,000 feet in New Jersey to about 7,000 feet in North Carolina. There are what might be taken as signs of a progressive rise of these elevations to the southward were it not that from the Smoky mountains of North Carolina there is a steep decline toward the gulf of Mexico, as well as a rise from New Jersey northward in ridges of related age, culminating in the White mountains of New Hampshire.

Taking first the Alleghanian field we find that the measure of accord in its summit levels is not what it seems at first sight to be. Looking from any summit which commands a wide prospect, the observer is always struck with the apparent regularity of the skyline of the distant mountains. On close study of this impression, however, he finds reasons to doubt its validity. It is easy to see that at a distance of, say 40 miles, differences of hight of 500 or even of 1,000 feet are not conspicuous unless the additional elevation have a peaked shape. If the rise is gentle at either end it is classed with the prevailing skyline formed by the other ridges. It is only by the careful inspection of good maps which by contours indicate the hights that an adequate conception of the altitudes of the reliefs can be gained. Until within a few years the hights of the Alleghanies were not enough known to afford a basis for this accurate inquiry. At present, however, the topographical maps of the area made by the United States Geological Survey are sufficiently accurate for the purpose. From them we learn that the range in the hights of the crests is considerable, amounting to as much as one-third of the maximum altitude above the plane of the sea, and to as much as one-half the hight to which the crests rise above the plane to which the greater rivers have cut down their channels. If these differences were presented to the eye in a group of peaks brought close together the hight relations of their summits would no more suggest the existence of an ancient elevated baselevel than do those of the Swiss Alps. It is rather the long, even skylines of their ridges than their likeness in hight that so distinctly suggests their origin in an elevated plain.

Problem of Appalachian Baseleveling

There are two sections of the Alleghany district which are especially noteworthy in this inquiry: One of them is the area about Cumberland gap, especially in the section adjacent to the headwaters of Cumberland river; the other in the drainage of the upper James river near Buffalo gap. In the first named area is an extensive tract of country where the ridges attain a hight of about 3,000 feet, rising to a considerable elevation above the neighboring crests. It is evidently a case where the superior hight is to be accounted for by the fact that we have there the node whence a number of streams radiate, flowing outwardly with a relatively slight fall, so that their cutting power is not great. In the second case. that near Buffalo gap, the excessive hight of Elliots knob is evidently due to its peculiar structure, which, in the absence of a strong attack by streams, has failed to go down as rapidly as the neighboring crests. These are but two instances out of many which go to show that the wide discrepancies in hight which exist in this region can be explained by variations in the conditions of down-cutting rather than by any reference to the problem of the original plane in which the erosion began.

We may fitly ask certain questions of those who hold to the hypothesis of an ancient elevated baselevel on which the erosion of the Alleghany section began. The first of these concerns the probable hight of the ancient surface above the present summits of the region. It is evident that it must have been very much above the plane of the existing crests. There are probably few geologists who would reckon the period in which this part of the Appalachian has been subjected to erosion since the Mesozoic period, when the supposed elevation took place, at less than ten million years, or the rate of down-wearing at less than 1 foot in 2,000 years. On this computation the original surface must have been 5,000 feet above the summits of the existing crests. Even if we halve this estimate we still leave the supposed plane very far up in the air—so far up indeed, that it does not seem reasonable to assume its sometime existence to account for the slight measure of uniformity which exists in the hights of the existing crests.

The evident difficulties of the view that holds for a baselevel control of the Alleghany ridges are increased when we come to consider the conditions of the country to the eastward. The Blue Ridge element of the Appalachian system is, as regards the hight of its peaks, even more irregular than the Alleghanies. While the last-named mountains exhibit a general decline to the southward, varied by a few remaining high points, the central ridge irregularly gains in altitude until the greatest hight is attained, in the western part of North Carolina. Yet it must be assumed that this portion of the Appalachian land was as much subjected to the baseleveling actions as the Alleghany area could have been. Its rocks, though harder, are more homogeneous than are the stratified beds on the west, and are, moreover, of a nature more readily to yield to chemical decay. Why, then, should baseleveling have been so effective in the district less than 40 miles to the west and failed to take effect here?

The question just above asked again comes before us when we examine the Piedmont area. We there find rocks in general character much like those of the Blue Ridge, together with newer strata essentially of Triassic age, which have been folded and faulted down into them, have been worn away until the mass forms a broad, rather uniform, field sloping gently from the hight of about 1,000 feet to beneath the level of the sea. So far as our knowledge of this and other continents goes, this area is in aspect one of the most characteristically baseleveled areas that is known, for in it an originally strong mountain topography, where rocks of exceedingly varied resistance are intimately commingled, have over a wide field been reduced to a nearly uniform surface, having a gentle inclination seaward. It is true that here and there isolated peaks surpass this plain, attaining to hights of several hundred feet above it; but although these features have a value in the interpretation, they in nowise deprive the district of its baseleveled character. Yet it appears impossible to explain the level surface of this area on the hypothesis that it has been worn down by river and atmospheric action. We can not apply this explanation, for the reason that the plain passes abruptly into the Blue Ridge, which rises above it to a hight from a few hundred feet in the Potomac valley to about 7,000 feet in North Carolina. It seems to me questionable whether any form of the baseleveling hypothesis will alone or even mainly account for this contrast in the character of the surface of these level and mountainous areas. So far as I can see, the only way in which the facts can be reconciled with that hypothesis is by the further supposition that the Blue Ridge has been separated from the Piedmont area by relatively recent faulting which has lifted the mountainous country to its high level. It is necessary to assume that this action took place after the baseleveling of the seaboard district was effectively accomplished. It is also to be noted that there is no evidence going to show that any such sufficient faulting has occurred. There are, it is true, abundant faults to be observed in the approximately level district of the shore belt, but these dislocations have had all traces of their original relief completely effaced. Moreover, the passage of the plain to the hills, although accomplished within a narrow belt, is in a measure gradual, showing no signs of sudden change such as would be exhibited if the conditions had been brought about by faulting alone.

It has been suggested that while the Piedmont district remains at or near its Cretaceous baselevel the country to the westward has been so differentially uptilted that the highest point of elevation is the Alleghanian field. To this hypothesis it may be answered that there is a lack of evidence sufficient for its support. The only point where I have been able to find any features which could be taken to afford such evidence is in the section of the James River canyon from the base of the Piedmont plain through the Blue Ridge and into the Alleghany field. The occurrence of many rapids in the lower reaches of James river suggests an uplifting action; but these features go to show that the movement which led to their formation was of relatively very recent age, and that it affected in something like an equal measure all the section from the sea border beyond the axis of the Shenandoah valley.

Discussion of Hypothesis of Baseleveling and of River spacing

While it can not be maintained that the evidence and arguments set forth in this paper are sufficient to determine a conclusion against the hypothesis of baseleveling as it is used to explain the approximate equality of summits throughout a considerably elevated area, it may fairly be claimed that they go to show the need of a more penetrating inquiry into the facts than has yet been essayed. When we consider that the advocates of the hypothesis in question have not yet shown us a region which has been and remains effectively baseleveled; when, moreover, we note that the changes in the relative level of the sea and land are not only frequently extensive, but evidently occur with a speed which is rapid in relation to the rate of down-wearing of the land, we may indeed begin to doubt the validity of the hypothesis that any such wide area as the eastern portion of this continent could ever have been so far worn down throughout its extent as to approach in aspect the supposititious plain which this view demands. There can be no question concerning the value as to the control which a baselevel of erosion exercises over the work of a river. The point yet to be determined relates to the efficiency of river work in bringing about the uniformity of hights in a mountain-built district. It appears to me that in the fields which I have been able to examine the effect arising from the interaction of the slopes of rivers spaced with an approximation of equality in interval and with like declivities will more satisfactorily account for the uniformity of elevation than the hypothesis which seeks to explain the coincidence by ancient baseleveling, with subsequent reelevation and denudation. It may well be that in many instances the results of the two groups of actions are intermingled.

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ORIGIN OF GRAHAMITE

BY I. C. WHITE

(*Read before the Society December 30, 1898*)

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ORIGIN OF NAME

The grahamite deposit of Ritchie county, West Virginia, was first described by Professor J. P. Lesley in a paper read before the American Philosophical Society March 20, 1863. The name (in honor of the Messrs Graham, who were largely interested in the mine) was given the mineral by Mr Henry Wurtz, the chemist, of New York city, who in 1865 published a "Report upon a mineral formation in West Virginia" for the Ritchie Mineral Resin and Oil Company of Baltimore, a corporation owning and operating the mine for the manufacture of illuminating gas and mineral oil.

In a paper dated October 14, 1873, and published in volume vi, second series, of the American Journal of Science, Professor William M. Fontaine gives a very full description of the mineral and its geological sur-

RELATION OF GRAHAMITE FISSURE OF RITCHIE COUNTY, WEST VIRGINIA, TO BURNING SPRINGS-EUREKA ANTICLINAL

roundings, and as this was only a few months before the mine was closed and abandoned, his paper gives the last and best description of the mine.

Investigations by Others

By reference to the papers in question the reader will discover that the grahamite fills a vertical fissure about two-thirds of a mile long, varying in width from a few inches at the ends to 4 and 5 feet in the center. The direction of the fissure is north 12 degrees west, and exactly at right angles to the great "Oil Break" anticlinal which, with dips from 30 to 70 degrees, crosses the measures about 7 miles west of the deposit.

Fontaine recognized the connection of the fissure with the upheaval of the measures on this Burning Springs-Eureka anticlinal, and the gifted Lesley foretold the origin of the grahamite in his first paper as follows: "This gash was once, no doubt, an open fissure, communicating with some reservoir of coal oil (petroleum) which still, it may be, lies beneath it undisturbed."

This hypothesis of Lesley, made 35 years ago, and without his ever having seen the region, has recently been verified in every particular.

Results of Exploration by Drilling

In 1890 a well was drilled for oil near Cairo, Ritchie county, 10 miles north of Ritchie mines, the locality of the grahamite, and an oil-pool developed in the basal member of the Pottsville conglomerate, or "salt sand" of the drillers. Since that time operations have gradually extended southward, until in 1897 the developments reached the region of the asphaltic deposit, and there, at a depth of 1,500 to 1,600 feet below the surface, was found, as Lesley had predicted, the pool of oil from which the grahamite was undoubtedly derived, since a prolific oil-field has been discovered in the immediate vicinity. The first well drilled in the region was located within 300 feet of the fissure, and hence, although some oil was obtained (one barrel daily), it was not in paying quantity, and no more drilling was done for several years.

The following record of the well drilled on MacFarlan run, Ritchie county, West Virginia, nearest the fissure, will give an idea of the geological succession in the region:

Record of Ritchie Mines Well

Material.	Feet.	Feet.
Unrecorded (cased $7\frac{5}{8}$ inches at 247 feet)	600 to	600
Black slate	57	657

Material.	Feet.	Feet.
Red rock	15	to 672
Black slate and shale	28	700
Red rock	40	740
Limestone and shells	10	750
Red rock	10	760
Light red shale	5	765
Red rock	20	785
Blue sand and limestone	15	800
Sand, gray, with show of oil	30	830
Hard shell of flint and limestone	10	840
Sand and slate (cased 6¼ inches)	30	870
Slate	10	880
Sand with limestone	10	890
Slate, dark	55	945
Sand, gray, with shell to bottom	15	960
Slate, light	10	970
Sand, gray	10	980
Coal	5	985
Slate, black	5	990
Sand, gray	15	1,005
Slate and sand	10	1,015
Slate	5	1,020
Sand, light gray and soft	25	1,045
Slate, dark	5	1,050
Sand	20	1,070
Slate	20	1,090
Sand, white (gas enough to run boiler)	15	1,105
Unrecorded	37	1,142
Sand, white	33	1,175
Break of slate	5	1,180
Sand, white	30	1,210
Slate	150	1,360
Sand, gray and coarse	20	1,380
Slate	8	1,388
Sand, gray and coarse	12	1,400
Shell	2	1,402
Slate, black	88	1,490
White sand ("salt," gas) 25 Sand (oil at 1,530) 15 } Cairo Oil sand	40	1,530
Sand	26	1,556
Slate	4	1,560
Sand, base of Pottsville	23	1,583
Limestone (Greenbrier)	67	1,650
Top of "Big Injun" sand (Pocono)		1,652

This well begins 140 feet below the Washington coal, and thus a few feet under the base of the Waynesburg sandstone. The coal at 980 feet is probably the Upper Freeport, though it may be lower than that coal.

Extent of Grahamite-bearing Fissure

The fissure holding the grahamite extends from the little valley of Mine run (a tributary of MacFarlan, where the well starts) up through the Washington coal and on to the tops of the hills 100 feet higher, while downward it extends to an unknown depth. When Professor Fontaine visited the locality the mine had been operated through a vertical distance of 300 feet, and he gives the following section of the beds exposed within the fissure in descending order:

Material.	Feet.
Gray shale	45
Sandstone	35
Gray shale (Washington coal in middle)	55
Sandstome, Waynesburg	95
Gray shale (boring begins in this)	55
Sandstone	30
Gray shale	20
Red shale to bottom.	

The higher summits above the top of the section are made up of a succession of red shales and brown or gray sandstones, typical members of the Dunkard Creek or Permian series.

Conversion of Petroleum into Grahamite

The development of the oil-field in this region of the grahamite deposit has been carried on chiefly by the Cairo Oil company, of which Mr W. K. Jacobs, of Cairo, West Virginia, is the superintendent. Mr Jacobs informs me that wells drilled near the fissure obtain good sand, but it acts like a drained or exhausted field, and produces oil in small quantity only, but that when the wells are located from 800 to 1,000 feet distant from the fissure good producers are obtained; hence there can be no doubt whatever that the fissure made by tension from the Burning Springs-Eureka uplift was filled with petroleum largely from the sand at 1,530 feet, which is the main producing rock of this region, though the "Big Injun" sand, below at 1,652 feet, may also have contributed something. Then the oil filling the fissure was gradually converted by subsequent oxidation from infiltrating water, etcetera, into grahamite without any heat other than that afforded by the temperature of the earth, since there is no evidence whatever of any disturbance of the rocks in the immediate region, aside from a gentle tilt common to the rocks of every oil-field. Hence the views of Wurtz and others that the grahamite originated from great heat, frying or baking the residuum out of bituminous shales and forcing it in a pasty condition into the fissure, is entirely erroneous, since the exhausted oil sand immediately under the region fully accounts for the formation of the grahamite.

Artificial production of Grahamite

Then, too, Mr Walter P. Jenney, in the April number of the American Chemist for 1875, describes how he produced in the laboratory a substance precisely similar in chemical composition to grahamite by passing heated air through Pennsylvania petroleum for several hours, so there can be no doubt of the derivation of grahamite from oil through the gradual escape of its volatile constituents and the oxidation of the residuum.

Origin of similar Substances

A corollary from this conclusion would be that the albertite of Nova Scotia has originated in the same way, and that gilsonite, uintaite, wurtzilite, etcetera, are all forms of oxidized petroleum, while Mr Diller, of the United States Geological Survey, believes that the " pitch " coal of Coos bay, Oregon, has also been derived from the same source.

The wonderful deposit of asphalt on the island of Trinidad, South America, has evidently originated from the upheaval, and the removal by erosion of the cover of an immense pool of oil, thus subjecting the oil to volatilization and oxidation. Had the clays, quicksands, and gravels which cover the great deposit of petroleum at Baku, on the Caspian sea, been elevated and eroded we should have a deposit of asphalt there similar to that on the island of Trinidad.

The graphites and other deposits of carbon in the Cambrian and pre-Cambrian beds are simply sheet-like outflows of petroleum oxidized and metamorphosed by atmospheric and igneous agencies respectively.

Relationship between Grahamite and Petroleum Deposits

Another corollary to be drawn from the conclusion that grahamite, albertite, and similar substances are derived from petroleum would be that in regions where these asphaltic deposits occur we may expect to find accumulations of petroleum, provided the rocks remain in a normal condition and are not too greatly disturbed.

Bituminous Material from Brooks Well

PLACE AND MODE OF OCCURRENCE

The Whiskey Run oil-pool was developed in Ritchie county early in 1898, and it lies about as far north from Cairo as the grahamite deposit does south from it. The oil occurs in the Big Injun sand, and in one of the wells on the Brooks farm a peculiar bituminous substance was encountered saturated with petroleum, and described by the drillers as tough and hard to penetrate—"drilling like rubber," as one expressed it. The deposit was reported as 8 feet thick, and lying directly on top of the Greenbrier limestone, or 67 feet above the Big Injun oil sand. Some of the material was washed out of the sand pumpings by Professor John F. Carll, the geologist, who kindly gave me samples for analysis, since its singular geological horizon suggested the idea that it might be grahamite.

GEOLOGICAL RELATIONS

The following record of Books well number 1, Whiskey Run oil-pool, received from Mr Carll, will show the geological relations of the mineral in question:

Record of Brooks Well Number 1

Material.			Feet.	Feet.
Unrecorded			530 to	530
Pittsburg coal			5	535
Unrecorded			505	1,040
Limy shale and sand			10	1,050
Unrecorded			50	1,100
Sand, grayish white			10	1,110
Unrecorded			90	1,200
Sand			20	1,220
Unrecorded			30	1,250
Sand			40	1,290
Coal, thin			..	....
Sand			10	1,300
Unrecorded			150	1,450
Coal			5	1,455
Unrecorded			145	1,600
Slate			10	1,610
Sand, white			70	1,680
Coal (?) (asphalt), saturated with oil			8	1,688
Big Lime (Greenbrier)			67	1,755
Big Injun	sand, fine, soft (oil at 1,761 feet)	10	73	1,828
	sand, white	5		
	sand and slate	4		
	sand to bottom	54		

SUGGESTED ORIGIN

The coaly material at 1,680 feet was found only in this Brooks well number 1, although many other wells have been drilled within short distances from it on the Brooks farm and others adjoining; hence it is possible that it may be some type of asphalt derived from the underlying petroleum of the Pocono or Big Injun oil sand.

CHEMICAL ANALYSES

Specimens of the material pulverized by the drill and preserved by Mr Carll gave the following proximate analysis to Professor B. H. Hite, chemist of the West Virginia Agricultural Experiment Station, compared with an analysis of grahamite made at the same time:

Material.	Brooks No. 1.	Grahamite.
Moisture	00.21	00.26
Petroleum	1.40	....
Volatile matter	34.21	58.37
Fixed carbon	48.82	39.24
Ash	15.36	2.13
Total	100.00	100.00
Sulphur	1.13	1.25

An ultimate analysis of another sample by Professor Hite gave the following results, compared with Mr Wurtz' analysis of grahamite:

Material.	Brooks No. 1.	Grahamite.
Carbon	59.20	76.45
Hydrogen	5.77	7.83
Oxygen	14.68	13.46
Nitrogen	1.01	....
Ash	19.34	2.26
Total	100.00	100.00

EFFECT OF SOLVENTS

The chemical composition of the material from the Brooks well, especially in its large quantity of oxygen, thus appears to be in fair agreement with grahamite, considering the large amount of ash or earthy material which it contains. The main doubt about its asphaltic nature is its behavior with the solvents of grahamite. It is only slightly soluble in them, and hence this leaves the question open for still further investigation, though its "drilling like rubber," limited (to Brooks well number 1) occurrence, and saturation with petroleum would appear to be strong evidence against its being coal.

OCCURRENCE AT OTHER LOCALITIES

Of the hundreds of oil wells drilled in the region, only one other has reported any *coaly material* at this horizon, and that was in Calhoun county, 30 miles south from Cairo. Here, on Leading creek, the Cairo Oil company drilled a well on the Metz land which gave the following succession, according to Mr W. K. Jacobs, superintendent:

Material.	Feet.	Feet.
Unrecorded	1,380 to	1,380
Sand	60	1,440
Slate	20	1,460
Unrecorded	85	1,545
"Salt Sand"	58	1,603
Slate	..	....
Unrecorded and sand	28	1,631
Coal (?) (asphalt)	5	1,636
Sand	2	1,638
Big Lime (Greenbrier)	106	1,744
Big Injun sand (gas, 1,788; oil, 1,809)	68	1,812
Slate and shells to bottom	25	1,837

The bituminous matter at 1,631, reported as coal by the drillers, may possibly have been of asphaltic origin, since it is situated along the same belt of country where the grahamite of Ritchie county occurs, and about the same distance east from the Burning Springs-Eureka anticlinal disturbance as the Brooks farm in the Whiskey Run oil-pool, where the other anomalous deposit of bituminous material was discovered.

Summary of Conclusions

From the foregoing there are drawn the following conclusions:

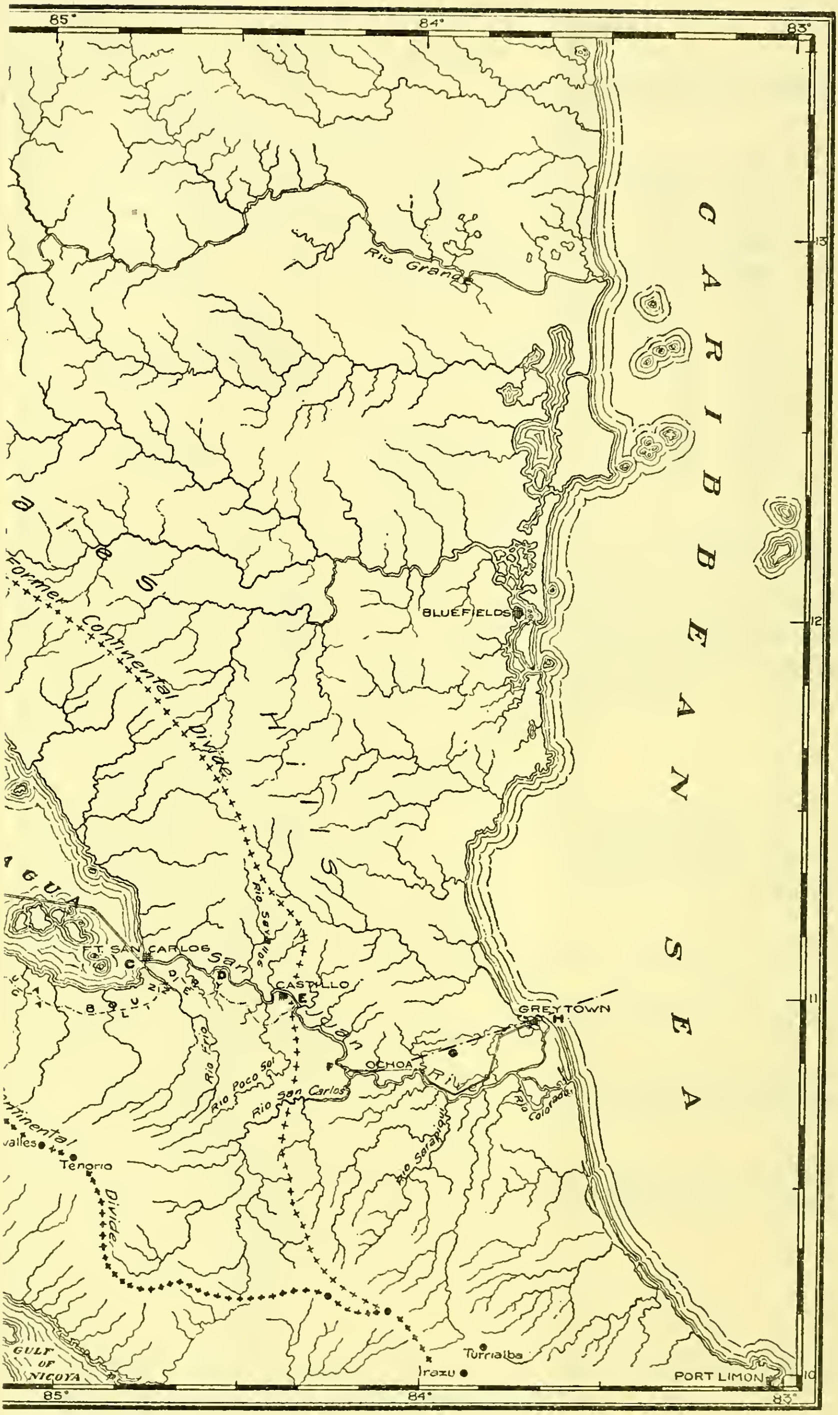
The fissure which encloses the grahamite of Ritchie county, West Virginia, was made by tension due to the upheaval of the measures along the Burning Springs-Eureka anticlinal.

Grahamite, albertite, gilsonite, and asphalt are all derived from the oxidation of petroleum.

The presence of these substances in undisturbed strata may be used as a guide to the discovery of oil pools.

Petroleum accumulations have taken place in all sedimentary beds from the earliest to the latest, and the graphite beds of the Cambrian rocks originated from oxidized outflows of oil.

Some outflows of petroleum appear to have occurred in the Cairo region of West Virginia at the close of the Lower Carboniferous epoch.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San Juan River
Rio Sabalos
CASTILLO
E
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OCHOA
G
GREYTOWN
H
Rio Frio
Rio Poco Sol
Rio San Carlos
Rio Sarapiqui
Rio Colorado
Continental Divide
Valles
Tenorio
Irazu
Turrialba
PORT LIMON
GULF OF NICOYA

ANAL ROUTE

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PHYSIOGRAPHY AND GEOLOGY OF REGION ADJACENT TO THE NICARAGUA CANAL ROUTE*

BY C. WILLARD HAYES

(*Read before the Society December 29, 1898*)

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*Published by permission of Rear Admiral J. G. Walker, President of the Nicaragua Canal Commission.

MAP OF REGION ADJACENT TO NICARAGUA CANAL ROUTE

INTRODUCTION

The region discussed in the following paper embraces northern Costa Rica and southern Nicaragua. Its special interest lies in the fact that it contains the lowest gap in the Continental divide between the straits of Magellan and the Arctic ocean, and probably also contains the most feasible route for an interoceanic ship canal.

In connection with the investigations of the canal route by the United States Nicaragua Canal Commission, the writer spent ten months of 1898 in field-work in the canal region, the greater part of which was in the direction of drilling operations. In this way much detailed information was obtained concerning the geology immediately upon the canal route, but little opportunity was afforded for a general examination of the adjacent region. The conditions which prevail over much of the country, however, especially the presence of a luxuriant tropical vegetation and the depth of rock decay, entirely prevent, or at least greatly hamper, ordinary geological field-work. The only way in which reliable information concerning the underlying rocks can be obtained is therefore by means of the drill. The lack of more extended observations is most seriously felt in the paucity of information concerning the physiography of the region on either side of the San Juan river formerly occupied by the Continental divide. This region is densely forested, and, having no roads, is very difficult of access. It contains very few permanent habitations, and is visited chiefly by native rubber-hunters, so that its characteristics are very imperfectly known. Western Nicaragua, on the other hand, is not heavily forested, and contains a relatively dense population. For these and other reasons information concerning this portion of the region is comparatively full.

Topography

GENERAL CHARACTER OF THE TOPOGRAPHY

The commonly accepted Humboldtian view of the topography of Central America should be definitely discarded at the outset. According to this view, which is still dominant in the text-books, a continuous mountain chain connects the Cordilleran system of western North America with the Andean system of western South America. Hill * has fully demonstrated the falsity of this old view and shown the complete independence of the orographic systems of the three Americas. The due east-and-west trend of the Central American mountain chains is perhaps less prevalent than Hill has represented it. In the region under discussion, at least, there is a distinct northwest-southeast trend in all the larger topographic features. The same trend predominates in the geologic structures, and the two are doubtless in some measure connected. The northwest-southeast trend is observed in the ranges of volcanic peaks which cross the isthmus diagonally from the Caribbean sea to the Pacific in northern Costa Rica and western Nicaragua. It is also, though less distinctly, seen in the Chontales hills between the Caribbean sea and the lakes, and again in the great depression which extends diagonally across the isthmus be-

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* Robert T. Hill: Fundamental Geographic Relations of three Americas. Nat. Geog. Mag., vol. vii, 1896, pp. 175–181.

tween the volcanic ranges on the southwest and the Chontales hills on the northeast.

CLASSIFICATION OF TOPOGRAPHIC FEATURES

Types in general.—Three distinct types of topography are encountered in this portion of Central America, namely:

Oldland areas with maturely developed degradational surfaces.

Recent volcanic cones and plateaus with slightly modified constructional surfaces.

Recent floodplains and deltas with still forming aggradational surfaces.

The oldland occupies much the larger portion of the region represented on the accompanying map. It forms most of the San Juan valley, and expands northward between the divergent lines of the Caribbean coast and the Nicaragua-Managua lake basins. It also forms the narrower portion of the land strip between the former lake and the Pacific. This part of the region appears to have been above sealevel since the middle of the Tertiary, and the form of its surface is due entirely to the action of subaerial gradational forces. Although composed largely of volcanic materials, the original constructional surfaces appear to be entirely obliterated.

The recent volcanic cones constitute two ranges—the Costa Rican range, terminating in the volcano Orosi, and the parallel Nicaraguan range, which extends from Madera northwest to the gulf of Fonseca. The eruptions which gave rise to the Costa Rican range appear to have broken out on a somewhat elevated land surface, perhaps similar in age and topographic development to the present Chontales hills. The northern series of eruptions, on the other hand, occurred on the sea bottom along a line near the center of a bay which formerly indented the Pacific coast. Most of the volcanoes constituting these two ranges are extinct, or at least quiescent, but they are so recent that their constructional slopes are only slightly modified by subsequent erosion. The same is true of the gently sloping volcanic plateaus from which rise the cones of the northern range.

The floodplains and deltas form a comparatively small part of the region, but their importance is out of proportion to their extent, particularly from the viewpoint of the canal engineer. By a recent depression of the land all the streams entering the sea have been drowned and the estuaries thus formed have been silted up. The deltaplains are the seaward extension of the floodplains, and hence are the most recent topographic forms of the region, and the method of their formation may still be observed in active progress.

The various topographic features mentioned in the above primary classification may now be taken up and described somewhat more fully. Since the oldland occupies the largest area and has more complex forms of relief, which are intimately connected with the recent history of the region, greater attention will be devoted to this division, and particularly to that portion of it which constitutes the Nicaraguan depression.

When examined in detail the surface of the oldland is found to have considerable diversity in its relief, and its topographic forms naturally fall into three classes. These are (1) fairly well developed peneplains, which rise gradually from either coast toward the axis of the isthmus until recent geologic time occupied by the Continental divide; (2) many valleys which intersect the surface of the peneplain, having been cut during a period of high level and subsequently depressed below sealevel, and (3) residual hills which rise distinctly above the peneplain surface and are most numerous toward the axis of the isthmus along the former Continental divide.

For convenience of description the valleys will be taken up first, and since these have been silted up by recent alluvial deposits, the floodplains and the coastal deltaplains will be described at the same time.

Alluvial plains.—The coastal plain on the Atlantic side of the isthmus increases from a mere fringe at the base of the mountains in Costa Rica northward to a belt from 10 to 15 miles wide in the vicinity of Greytown. It is formed wholly of materials brought down by the rivers heading in the Costa Rican volcanoes—is in fact a series of coalescing deltas, of which the largest is that formed by San Juan river. The sediment brought down to the sea by streams north of the San Juan is very small compared with that brought down by those to the south. The more rapidly growing southern deltas would therefore be extended seaward except for a strong northward littoral sand current set up by the oblique direction at which the prevailing winds strike the shore. The true littoral current in this portion of the Caribbean sea is to the southward, but its capacity for transporting sediment is more than neutralized by the active northward sand drift within the zone of surf action. This sand drift tends to distribute the sediment evenly along the coast and preserve gently curving coastlines. Notwithstanding this tendency, the San Juan delta has been built out a short distance into the Caribbean, forming a shallow embayment to the northward of Harbor Head.

The level surface of the deltaplain is interrupted by numerous low rounded hills composed of residual clay derived from the decay of rock *in situ*, and differing decidedly in appearance and composition from the surrounding alluvium. These hills have the form and appearance of islands rising above the level deltaplain, and it is quite probable that they were at one time islands fringing the shore before the alluvial deposits extended out to them and connected them with the mainland.

The inner margin of the deltaplain is extremely irregular. The isolated hills increase in number and size and finally merge with the dissected interior highland, while the deltaplain itself merges with the broad floodplains of the streams.

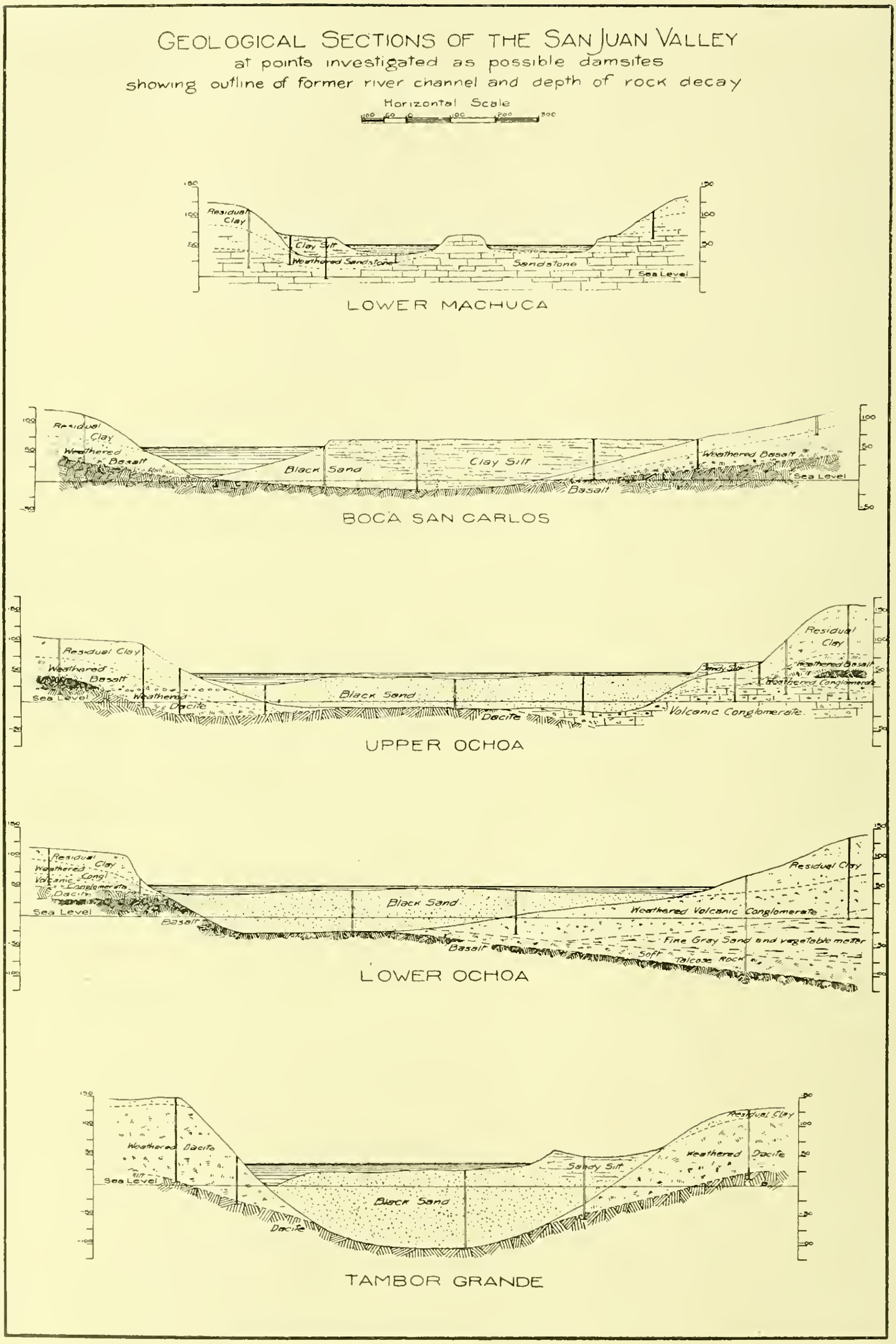
The surface of the deltaplain in its seaward portion is but a few feet above tidelevel. Its extreme outer margin is marked by low ridges parallel with the shore, formed by the sand thrown up during exceptional storms. From the shore margin the surface of the plain ascends toward the interior at a fairly uniform rate of about 28 inches to the mile.

The surface of the deltaplain is also diversified by numerous small lakes and lagoons. These are produced chiefly by the formation of sandspits and by unequal sedimentation.

Sediment is delivered by the larger streams slightly faster than it can be distributed by the littoral current; hence it tends to build out a delta; but this is deflected in the direction of the current and forms a curved sandspit, which for a time makes a well sheltered harbor. As the sandspit continues to grow, however, its point eventually joins the mainland, and the harbor is converted into a closed lagoon. This complete cycle of changes has taken place at Greytown during the last century and a half. The cycle has also been repeated at the same point several times previous to the last, giving rise to the several distinct lagoons which occur back of the one last formed.

The second method by which lagoons are formed on the deltaplain is by unequal sedimentation. As the coast was built outward by additions to its outer margin it advanced past numerous islands fringing the shore and which in some cases prevented the uniform deposition of sediment by interrupting the littoral sand stream, and these areas, in which little or no deposition took place, subsequently formed lakes. Perhaps the best example of a lake formed in this manner is lake Silico. This occupies what was evidently at one time a bay sheltered by the Silico hills, which then formed a group of islands. As the deltaplain was built out, connecting these islands with the mainland, the sheltered bay was not filled by sediment, but its opening was cut off and a lake thus formed.

Another class of lakes or lagoons formed by unequal sedimentation is found about the margins of the deltaplain and the river floodplains. The rivers which head upon the Costa Rican volcanoes carry a much more abundant supply of sediment than the smaller streams which flow from a region composed of compact residual clays protected by a heavy mantle of vegetation. Hence the floodplains of the larger streams, as the San Juan, are built up more rapidly than those of their tributaries.



GEOLOGICAL SECTIONS OF SAN JUAN VALLEY, NICARAGUA

The latter are therefore dammed and form lagoons in their upper basins. The Florida lagoon is a typical example of this class.

The lagoons of the deltaplain formed in these various ways are at first open lakes, but they gradually become choked by vegetation and filled with fine silt, so that they are converted into grassy marshes, and finally, when the silt becomes sufficiently consolidated to form a stable support, the forest trees encroach on the marsh and all trace of the lagoon is lost. Numerous examples occur on the deltaplains illustrating every step in the process: first the open lagoon, then the floating grass mat, then the silico swamp, and finally the heavy forest.

As already indicated, the deltaplain at its inner margin merges with the broad floodplain of the San Juan river, and any line separating the two would be purely arbitrary. For convenience, however, the head of the delta may be placed at the point where the first distributary, the San Juanillo, leaves the main stream.

Most floodplains are formed by the lateral cutting of streams as they swing from side to side in their valleys. A plain thus cut in the underlying rocks is usually covered with a thin sheet of alluvial material. The floodplains of this region, however, belong to a totally different class. They include no level plains cut in the underlying rock or residual material which covers the rock. On the other hand, the alluvium has very considerable depth, and, instead of forming a layer of uniform thickness, fills a series of old stream channels. It is evident that these channels were formed when the land stood higher than now, for many of them extend below sealevel. There is thus an old land surface concealed beneath the alluvial deposits, and a consideration of its topography becomes a matter of prime importance to the engineer. This buried topography will be considered more fully in connection with the unburied portion of the same surface—that is, the surface of the hills rising above the margins of the alluvial plains (see plate 31).

Extensive floodplains extend up the San Juan river to the mouth of the San Carlos. Above this to the head of the Toro rapids the river flows in a comparatively narrow gorge, and its floodplains are narrow and inconspicuous. From the Boca San Carlos downward to the head of the delta, floodplains are always present on one or both sides of the river, though they are most extensively developed on the south side. The surface is slightly higher near the river, forming the natural levee which characterizes most floodplains. The outer margins are depressed and occupied by swamps or lagoons. The surface of the floodplains in the vicinity of the Boca San Carlos varies from 15 to 20 feet above the river at ordinary low stages. As the plains become more extensive downstream their surface is slightly less elevated, since the floods which deposit the alluvium, having opportunity to spread over a much larger area, do not rise so high.

The slope of the floodplains from the Boca San Carlos to the head of the delta is about 11 inches per mile. This slope is dependent on the volume of the river and the character and quantity of the sediment which it carries. It is therefore much steeper below the mouth of the San Carlos than above, for it is from this stream that the greater part of the coarse sediment in the lower river is derived.

As stated above, the floodplains are inconspicuous from the Boca San Carlos to the head of the Toro rapids. The river flows in a comparatively narrow gorge and is generally bordered by rather steep hills, which approach nearly to the river channel. At the head of the Toro rapids, however, the valley widens, and from this point to the lake the river is everywhere bordered on one or both sides by extensive floodplains. Although their general relations to the river are similar to those bordering its lower course, they yet differ in some important particulars. They have been formed by sediment borne, not by the river itself, but by tributaries coming into the valley on either side. They thus have the form of coalescing deltas. The natural levee, which is a conspicuous feature in the floodplains of the lower river, is absent, and the plains generally show a gradual descent from their outer margins toward the river. Hence there are no lagoons on the tributaries such as are found on the tributaries of the lower river, and the floodplain becomes gradually firmer and more heavily wooded with increasing distance from the river. From the mode of formation of these plains it is manifest that the river is in a stable position and does not show that tendency to seek a new channel which is characteristic of delta streams.

Most of the streams entering lake Nicaragua on its northeastern side at one time entered the heads of estuaries. These estuaries have been almost entirely filled with alluvial deposits, and in some cases somewhat extensive deltas have been built out into the lake. The absence of a surf in this portion of the lake, except on rare occasions, owing to the direction of prevailing winds, permits the building of deltas which carry the distributaries of the streams a considerable distance out from the general shore line. The most extensive alluvial deposits about the lake are at its southern end. This portion of the lake basin appears to have been originally rather shallow, and the sediment brought in by streams from the south, notably by the Rio Frio, has considerably contracted its area. The newly added land forms about the margin of the lake an extensive swamp, through which the streams meander in a network of interlacing distributaries, all more or less obstructed by vegetation. The land becomes gradually firmer at increasing distances from the lake, and finally passes into an ordinary alluvial floodplain. Streams entering the lake from the southwest in general flow in channels which were at one time excavated to a very inconsiderable depth below the present surface of the plain through which they flowed. This plain, it may be remarked in passing, is not alluvial, but is a plain of degradation; hence these streams are bordered by very inconsiderable alluvial plains, and that only near the lake. The streams entering the Pacific from this portion of the isthmus are all short and consequently small, since the Continental divide is near the west coast. They occupy valleys which have been cut to a much greater depth than they have at present, and these old valleys have been recently drowned and more or less perfectly filled with alluvial deposits. Where the filling is not quite complete an estuary occupies the old river valley and forms a harbor, as is the case at San Juan del Sur. Where the filling is complete, as in the valley of the Rio Grande, the headlands which mark the margins of the former deep valley are connected by a curved beach, which does not indent the coast to any appreciable extent. The depth of the alluvium in the Rio Grande valley varies from about 40 feet at the head of the floodplain to something over 100 feet at the coast. The stream which has filled this valley carries at certain seasons an abundant supply of sediment, so that the seaward slope of the floodplain is rather steep, a little over 10 feet to the mile. The conditions in this region which determine the rate of erosion are much more favorable to rapid degradation of the surface than in the region of much greater rainfall to the east, where the rain is distributed evenly throughout the year. The streams are alternately shrunken to mere rivulets and swelled to torrents, and the resulting floodplain has somewhat the character of an alluvial cone.

Dissected peneplain.—The group of topographic forms to be described next in order after the alluvial plains consists of a more or less completely dissected plain or peneplain of degradation. In order to understand the present topography it is necessary to consider the original form of this plain and the manner in which it was developed. The conditions which prevailed prior to its formation cannot be definitely determined, but may be inferred in a general way. There was probably a somewhat elevated plateau, growing broader and higher both to the northward and the southward from a somewhat constricted region, now occupied by the Nicaraguan depression. The Continental divide at that time probably occupied a position near the central part of the isthmus, crossing the present San Juan valley in the vicinity of the Castillo rapids, and streams heading upon this divide flowed to the seas on either side. Another important difference was in the form and position of the Pacific coastline. These differences in the geography of the region, so far as they can be inferred, are represented on the accompanying sketch map (plate 30). It will be noted that lake Nicaragua did not then exist. Its present basin was occupied in part by a bay indenting the coastline and in part by the basins of rivers tributary to this bay. The region occupied by the volcanic peaks of the Nicaraguan range and the volcanic plateau west of the lake was then occupied by the sea. A cape projecting northward between the sea and the bay was composed of low hills, now forming the Continental divide southwest of the lake.

In still other respects the drainage of the region during the formation of this peneplain differed from the present. The San Juan river receives only small tributaries from the north, while it receives both small and large from the south. The large tributaries include the Frio, Poco Sol, San Carlos, and Sarapiqui. These all head on the slopes of the Costa Rican volcanic range, which forms the southern margin of the Nicaraguan depression. The upper portions of these streams are normal to the mountain range, the axes of their valleys being at right angles to the axis of the range, and also to the general course of the San Juan. Midway of their courses, however, there is an abrupt change in direction. The Frio and Poco Sol bend westward, while the San Carlos and Sarapiqui bend eastward, the axes of the lower valleys in every case making a rather acute angle with the course of the San Juan. It seems probable that when the peneplain was being developed in this region the two rivers whose basins now form that of the San Juan occupied the axes of those basins, receiving tributaries of equal length from either side. The volcanic eruptions to the south, however, obliterated the former drainage of that region, and the consequent streams developed on the flanks of the newly formed mountains were turned northeast, discharging into the heads of the preexisting small tributaries. It thus appears that the four above named southern tributaries of the San Juan have composite courses. Their upper courses, normal to the trunk stream, are consequent on the constructional slope of the recent volcanic range; their lower courses, making acute angles with the trunk stream, are inherited from the normally developed, small tributaries of two streams flowing respectively southeast and northwest.

The rapidity with which the streams heading upon the Continental divide reduced their valleys to baselevel depended chiefly upon the character of the rocks which they encountered, while the rate at which the divide was lowered by the action of opposing streams depended on the character of the rocks and the distance of the divide from the coast or the width of the isthmus. The region to the northward is probably occupied by the older and more resistant rocks, including gneisses, schists, and quartzites. Of that to the south very little is known, since its topography has been entirely changed and its older rock formations concealed by the recent eruptions of its volcanoes. From this combination of circumstances it followed that the surface was most completely degraded and the divide most rapidly lowered along a belt extending diagonally across the isthmus and now forming the great Nicaraguan depression. A broad river basin was developed on the east side of the divide, occupying the present position of the lower San Juan basin. The land between its various southern tributaries was reduced to low relief. Its northern tributaries were separated by somewhat higher hills, probably the result chiefly of the greater original elevation of this portion of the region. Another river system developed a similar basin with its outlet to the west. The several upper tributaries of each of these two river systems headed on the Continental divide in low gaps against the tributaries of the other system. The basin of the western system was somewhat larger than the one on the east of the divide. Its lower portion was separated from the Pacific by a range of hills which continued northwestward, forming the cape between the then existing bay and the ocean. The southern portion of the present basin of lake Nicaragua was occupied by this river system, and extensive plains were developed on either side of the axis extending up the tributaries as broad valleys well back into the surrounding hills.

The foregoing brief account of the original extent of this peneplain and the manner in which it was formed is an essential preliminary to an understanding of the present topography. At the conclusion of the long period of degradation, during which the surface of the region now occupied by the Nicaraguan depression was reduced to a low relief, the land was slowly elevated until it stood some hundred feet higher than before and perhaps 200 feet higher than now. The elevation stimulated the streams to renewed activity, and they began trenching the valleys which they had previously formed. The erosion was at first most active near the coast, and worked backward toward the interior most rapidly along the largest streams. The portions of the peneplain most completely dissected were therefore its outer margins. Here the surface was almost entirely reduced to the lower baselevel, and only a few rounded hills on the divides retained any trace of the former plain. The first of these remnants seen on ascending the San Juan are in the vicinity of the delta head where low hills approach the river on the north side. This region, however, has been so deeply dissected that the hilltops scarcely suggest the existence of a former plain. Other hills of similar character occur along the river, chiefly on the north side, although the most prominent hills which come down to the river do not belong to the group now being described, but to the residual hills which rose above the surface of the old plain at the time of its most perfect development. The remnants of the dissected plain increase in number and in the regularity of their summits until, in the vicinity of Ochoa, their uniformity is such that the position of the old peneplain can be accurately determined. The dense tropical forests mask the minor topographic features, so that the uniformity in the summits of the hills is not at once apparent. The detailed contour maps, however, of those portions of the region which have been actually surveyed exhibit the uniformity in a striking manner. The present elevation of the hilltops in this region is about 150 feet above sealevel. To the south of the river the old plain was very extensively developed, and while it has suffered much subsequent dissection, there is a large area in which its former position can be readily determined by the summits of the present hills. To the north of the river it was less extensive, forming only broad valleys between the residual hills which occupied the divides. Although not so extensively developed here as south of the river, the plain has been somewhat better preserved, and many streams are found which have not yet lowered their valleys appreciably below the old surface. Heading on the steep residual hills, their upper courses are in sharply cut V-shaped valleys. Emerging from these, they flow in shallow valleys across the remnant of the old plain, their channels meandering and obstructed by swamps. Farther down they enter narrow gorges which they have cut and are still deepening in the old peneplain. Still farther down they are bordered by alluvial plains, where the valleys which they cut in the old plain have been depressed below baselevel and so silted up.

Continuing westward from Ochoa, the summits of the hills become less uniform in altitude, corresponding with the originally less perfect development of the old peneplain in the vicinity of the former Continental divide. Along the upper portion of the river, west of the Toro rapids, are numerous low, rounded hills merging on either side of the valley with a more continuous upland, and these probably mark the position of the former peneplain. It slopes gently westward and probably passes beneath the waters of lake Nicaragua. The broad valleys bordering the streams which enter the northeastern side of the lake and the level plain which forms the western margin of the lake basin probably constitute parts of this old plain, which have here almost entirely escaped dissection.

In connection with the remnants of this old peneplain, the topography of the surface now concealed by the alluvial deposits should be considered. At the close of the period of high level, during which the plain was dissected, the valleys were rather narrow with steep slopes except near the coast. If the subsidence which inaugurated the period of alluviation had occurred all at once, tidewater would have extended up the valley of the San Juan river beyond the Boca San Carlos, and also some distance up its tributaries. It is probable, however, that the land sank very slowly, so that the estuaries were never deep, but were filled by alluvium almost as fast as formed. The depth of these old valleys having been determined by borings at various points on the trunk stream and some of its tributaries, it is possible to reconstruct the former surface and determine approximately the depth of the alluvial filling in any part of the drainage system. It is found that the erosion of the hills has been inconsiderable, since the submergence for the slopes above the margin of the floodplains are practically the same as the old slope beneath the alluvial cover. The valleys of the lower San Juan and its tributaries have been filled in such a manner that the present streams follow very nearly the same course as the streams which formed the valleys. In some cases their meanders have carried them to one side or the other of the old valley, where they are now cutting against the bordering hills of residual clay. The form of the old San Juan valley is shown on plate 31.

The original form of the surface concealed by the floodplain of the upper San Juan is much more difficult to make out. This plain was formed by deposition in quiet water, the river valley being entirely drowned. Hence the present channel was not determined by the deepest portion of the old valley, but by the relative amounts of sediment brought into this portion of the lake by tributaries on either side. It is evident that the stream bearing the largest amount of sediment is the Rio Frio, and the delta of this stream has pushed the outlet of the lake northward away from the deeper portion of the old valley and against the hills which formed its margin. The same thing is seen at various points between the lake and the Toro rapids. At numerous points the meanders of the river carry it away from the deeper portions of the old valley and against the marginal hills. In most cases these meanders are not accidental, but are determined by the entrance of a tributary on the opposite side. It is therefore impossible to determine the position of the stream which formerly occupied this valley from the present position of the San Juan. Sufficient boring has been done in this portion of the river channel, however, to determine the fact that the rock or residual clay slopes of the hills which at present rise above the alluvial plain continue practically unchanged beneath the alluvium. The importance of this fact in the location of the canal line is at once apparent. The line in general follows the channel of the river, but if this were strictly followed considerable rock excavation would be necessary where the channel swings against one of the marginal hills. It is evident, however, that by shifting the line away from the hill the rocky slope will pass below the bottom of the canal, so that the excavation necessary to secure the required depth will be entirely in alluvium.

Residual hills.—The third group of topographic forms which characterize the old land area embraces the hills rising distinctly above the present tops of the lower hills and representing portions of the surface never reduced to the level of the old peneplain. The summits of these hills are entirely different from the dissected remnants of the peneplain above described. The crests are always sharp and serrate, with no uniformity whatever in their altitudes.

The hills of the Eastern divide lying between the basins of the Deseado and San Francisco form a characteristic group belonging to this class. Their slopes are extremely steep and their sides are furrowed by sharp V-shaped ravines. Around their base are remnants of the old plain above which they formerly rose, now appearing as rounded hills with uniform summits. Long spurs radiate from the central mass of the Eastern Divide hills and reach the San Juan river at several points, forming the high ridges at Sarapiqui, Tamborcito, Tamborgrande, and San Francisco. Another prominent group of hills belonging to this series occurs at the junction of the San Juan and San Carlos. These have a form similar to that of the Eastern Divide hills, but the group is somewhat smaller. The upper slopes are extremely steep and the sides are deeply gullied, while the summit as seen from either side presents a sharply serrate outline. The altitude of the San Carlos hills is about 1,200 feet. These isolated groups of high hills occur with increasing frequency toward the line formerly occupied by the Continental divide, which probably crossed the present valley of the San Juan in the vicinity of Castillo. West of this line they decrease in frequency and hight to the lake.

The residual hills which rise above the peneplain of the Nicaraguan depression increase in hight and numbers toward the north, finally merging with the mountains of northern Nicaragua, where they reach elevations from 6,000 to 7,000 feet above tide. Comparatively little is known of any portion of this region except its western margin. The eastern part is covered with a dense tropical forest, is almost entirely without settlement, and has been only partially explored. The divide between the lake and Caribbean drainage passes some distance to the westward of the axis of the isthmus, being approximately parallel with the Pacific coast northwestward to the Matagalpa river, where it makes an abrupt bend to the eastward, passing around the basin of that stream. This region between the lake and the Caribbean may be described as a deeply dissected upland. During Tertiary time it was doubtless the locus of intense volcanic activity, but subsequent erosion has entirely destroyed all trace of the original constructional topography, and the location of the vents by which the volcanic rocks were erupted can not be determined from the present form of the surface, though it might be determined by a systematic study of the distribution and variations in character of the volcanic rocks. Toward the northern end of the lake, opposite Granada, the summits of the hills present an even skyline, as though they were remnants of a plateau; but this surface may be a degradational rather than a constructional plain. The streams flowing into the lake have baseleveled their valleys for a considerable distance back into the upland, but are separated by sharp ridges and hills which occupy the divides. Although the higher portions of the divides attain somewhat uniform altitudes which increase northward, the uniformity is not sufficient to determine the former existence of a distinct plain, and it is probable that the present valleys are carved in a surface which, since its final emergence above sealevel, has always had rather high relief.

Western divide.—As already indicated, the great Nicaraguan depression was formed before lake Nicaragua came into existence. It originally extended entirely across the isthmus, terminating to the westward at the bay which then indented the Pacific coast, a cape projecting to the northwest between this bay and the ocean. The cape now forms the narrow strip of land lying to the southwestward of lake Nicaragua and separating it from the Pacific. This strip of land is not properly, therefore, a part of the Nicaraguan depression, and its topography should be independently considered.

Bordering the southwestern shore of the lake and extending northwestward nearly to Zapetara island is a very perfectly baseleveled surface, termed for convenience the Rivas plain. It varies in width from 5 to 12 miles, and is continuous along the lake margin, except near the Sapoa river, where it is interrupted for a short distance by high hills coming down to the lake. Very little is known concerning the southeastern extension of this plain, but it is probably nearly or quite continuous around the end of the lake with the peneplain of the Nicaraguan depression already described. Its northeastern margin is the lakeshore, where the waves have cut a shallow terrace backed by a cliff from 10 to 40 feet in hight. A few low, rounded hills rise above its even surface, but they seldom attain hights of more than 100 feet. In the vicinity of Rivas, where it is most thoroughly known, the plain ascends toward the southwest, at the rate of about 8 feet to the mile, to the base of the hills which occupy the greater part of this strip and form the Continental divide. These hills rise abruptly from the Rivas plain to hights of 800 to 1,200 feet above tide, and extend northward to a point opposite the island of Zapatera, where they meet the Jinotepe plateau, and the serrate residual outline of the former gives place to the even constructional slope of the latter. A single break occurs in this continuous line of hills. This is the gap between the waters of the Rio Lajas and of the Rio Grande. Here the level plain bordering the lake extends entirely through the range of hills, forming a low, broad gap whose summit is but 50 feet above the lake.

The manner in which this single low gap was formed is described at some length in a later part of this paper, where the recent geological history of the region is given. It may be stated here, however, that the gap is the product of the familiar process of stream capture. Owing to the decided advantages possessed by the streams flowing directly to the Pacific over those flowing eastward, at first to the bay of Nicaragua and afterward to the lake, the former were able to cut back through the divide into the drainage area of the latter and to divert their headwaters. In this way an eastward-flowing stream originally occupying the position of the Tola, the upper Rio Grande, the Guiscoyol, and the Lajas was beheaded, and the drainage of a large part of its basin was diverted to the Pacific. The deserted valley of this stream forms the low gap through which the canal route is located. It is so broad and level that accurate instrumental work is required to determine the actual summit of the Continental divide.

The Pacific coast in the southern part of this region is formed by alternating short strips of sandy beach and bold, rocky promontories. The stretches of beach are formed by the silting up of deeply cut valleys, and the promontories by the truncated points of ridges which extend down to the coast between the valleys. To the northward of Brito the proposed western terminus of the canal, at the mouth of the Rio Grande, the hills are farther inland and fewer spurs reach the coast. A coastal plain of some extent is here developed, increasing in width to the north until it passes beneath the recent volcanic deposits which form the Jinotepe plateau.

This coastal plain probably at one time passed around the northern end of the divide hills and was continuous with the Rivas plain to the east. With the formation of the Jinotepe plateau the tuffs of which it is composed buried this northern portion of the plain and piled up against the end of the divide hills three or four hundred feet in thickness.

Lake-Caribbean divide.—The much greater rainfall in the eastern portion of the isthmus has given the Caribbean streams a decided advantage, and they have pushed the divide westward probably some distance from its original position. A few cases occur which clearly indicate stream diversion. The most striking of these is the upper portion of the Rio Grande, which flows to the Caribbean north of Bluefields. This river heads in the high valley of Matagalpa, from which it flows southwestward for 35 miles, approaching the Viejo within about 5 miles, being separated from that stream by a level swampy plain. The Viejo flows southwest to the upper end of lake Managua, and it is entirely probable that the upper portion of the Rio Grande was formerly a tributary of the Viejo. From the point where it approaches most nearly to the Viejo it flows southward for a distance of 25 miles, and this southerly direction is continued in a tributary which enters at that point. This portion of the stream appears to have been at one time a part of the Malacapoya, which enters the head of lake Nicaragua. From the point of nearest approach to the Malacapoya the Rio Grande turns abruptly back to the northeast, and for a distance of 30 miles is approximately parallel to its upper course in the valley of Matagalpa. It appears highly probable that the Rio Grande, by reason of the greater rainfall in the eastern part of this region, pushed the divide westward until its headwaters intercepted the upper portion of the Malacapoya. The same process was continued and the extended headwaters effected another conquest, diverting a large tributary of the Viejo. The latter capture has been so recent that the channel of the diverted stream has not been perceptibly lowered, and a part of its waters in the wet season may still follow their former course to the Viejo across the intervening swampy plain. A few other cases of stream diversion are indicated by the character of the present stream channels, but none of them are so striking or important as that of the Rio Grande.

Volcanic mountain ranges.—As indicated above, the southern margin of the Nicaraguan depression is formed by the foothills of the Costa Rican volcanic range. This range terminates to the northwestward in the probably extinct volcano Orosi. It contains a large number of volcanic peaks, most of which are extinct and a few quiescent or moderately active. These peaks have a striking linear arrangement and form two nearly parallel lines of vents. The line terminating in Orosi extends southeastward into Costa Rica, passing to the southward of a parallel range whose northern peak is the volcano Turrialba. These two lines are about 10 miles apart, but their peaks are so high that their slopes merge and they form a single range. If the line connecting the northeastern series of peaks were continued to the northwestward through the southern portion of lake Nicaragua it would coincide very nearly with the line connecting the peaks of the Nicaraguan range. The latter range terminates to the southward in the extinct volcano of Madera; thence it stretches to the northwest, terminating in the volcano Coseguina, which occupies a peninsula projecting into the gulf of Fonseca. Between these two extreme peaks there is a large number of extinct, quiescent or active volcanic vents forming more or less isolated mountains. Of these Ometepe, Masaya, Momotombo, and several others to the northwest of the latter have been in eruption within historic times. Others are in the solfataric stage, while still others appear to be entirely extinct. The group of peaks between Momotombo and Coseguina is called the Maribios range.

It is probable that the vents which formed the Costa Rican range broke out upon a somewhat elevated plateau, while those which formed the Nicaraguan range broke out on the sea bottom. The latter, also, are farther apart, except those northwestward of Momotombo, which form the Maribios range. This may explain the greater hight and massiveness of the Costa Rican range, and the amount of material erupted from the two series of vents may not differ greatly.

As already indicated, it is probable that the form of the coast has been materially modified by this recent volcanic activity. The whole of the country between the northern portion of lakes Nicaragua and Managua and the Pacific consists entirely of recently ejected volcanic material, and the region which it now occupies was doubtless a portion of the Pacific until recent geologic times. The former coastline is represented on the sketch map forming plate 30.

The surface of this newly added land is composed of level or gently sloping plains, isolated conical volcanic peaks, and the more crowded peaks of the Maribios range. Types of the entirely isolated peaks are Ometepe and Momotombo. Both of these are composed of alternate layers of lava and ash. The latter, however, gives them their perfect conical form. Both have been in eruption within historic times, and considerable smoke still comes from Momotombo. Only a small amount of steam and sulphurous vapors are at present emitted from the crater of Ometepe.

Modification by the ordinary processes of erosion, in the form of these steep cones of unconsolidated ash, is extremely rapid, and their summits vary in detail of outline from year to year. Madera and Zapatera are volcanoes, which have been extinct for some time, and the agents of degradation have materially reduced their hight and destroyed the original conical form of their summits. The unconsolidated ash has been largely removed from their upper portions, leaving only the massive lava beds in place; hence their formation has been ascribed to a different form of eruption from that which produced Ometepe and Momotombo. It is probable, however, that the summits of the former once consisted of ash cones, and that the eruptions in all have been accompanied by more or less explosive violence, to which the unconsolidated fragmental material is due. The lower slopes of Mombacho are rather smooth and symmetrical; but instead of a single cone its summit is truncated and forms a series of ragged peaks, which surround a deep depression occupied by a small lake. There is a tradition that this mountain formerly had a conical summit, which was destroyed by an explosive eruption. The present appearance of the mountain makes it extremely probable that this tradition is based upon fact. Its outline closely resembles that of Coseguina, and, as is well known, the latter was formerly capped by a symmetrical cone, which was blown off in the explosive eruption of 1835. This was perhaps the most violent recorded eruption of this character up to the time of the eruption of Krakotoa in 1883. Since this final burst of activity Coseguina has remained perfectly quiet. The volcano of Masaya, which erupted a flow of lava in 1858, is at present a mountain of moderate hight, about 2,200 feet. It occupies the position, however, of a mountain which may once have been very much higher. The former volcanic peak occupying this position was destroyed, not by an explosive eruption, but by engulfment. The peak now occupies a depressed area, having an oval shape and regular outline, about 4 by 6 miles. It is located a little north of the center of this depression, the northern portion of which its lavas have nearly filled, flowing out over the edge at several points on the surrounding level country. The outlines of the depression, however, can be traced continuously with the exception of these few breaks, where its rim has been overtopped by the recent lava. It is nearly everywhere a vertical cliff, descending abruptly from the level or rolling plain. The southern end of the depression, which is not filled by the lavas of Masaya, is occupied by the waters of lake Masaya. The lake has a crescentic form and is bordered on the convex side by the vertical cliffs of the caldera wall rising 360 or more feet above its surface. On the concave side it is bordered by the gentle slope of the lavas of Masaya. It appears almost certain, therefore, that a portion of the volcanic plateau and perhaps a volcanic cone of considerable hight have disappeared by engulfment; but that a subsequent eruption at the same point has partially filled the depression, building up a new cone over the same vent, though not to so great a hight as the former one. This new cone is Masaya. It has the rather low dome shape characteristic of cones composed largely of lava flows, and is broadly truncated by a double crater. A similar engulfment has occurred south of Masaya, forming the present lake Apoya. The depression did not coincide with a volcanic cone, but occurred on the northern side of mount Catrina, a low ash cone, carrying down one side of the latter and a portion of the adjacent plain. The depression is somewhat smaller than the one occupied by the lake and volcano Masaya, being about 4 miles in its largest diameter and nearly circular. The depression is now occupied by the waters of lake Apoya, which are 260 feet below the lowest point of the surrounding rim and about 1,500 feet below the highest point of the rim. This highest point probably coincides very nearly with the former volcanic peak, although the latter, being composed almost entirely of unconsolidated ash, has been very much reduced in hight by erosion. Several other caldera lakes of this type occur in the vicinity of Managua.

Volcanic plateaus.—Reference has been made to a plateau lying southwest of lake Managua and the northern end of lake Nicaragua, which I have called the Jinotepe plateau, from the principal town on it. This plateau is composed entirely of recently ejected volcanic material, chiefly a partially consolidated volcanic tuff, which was spread out probably in the form of a semi-liquid mud. The plateau has an altitude along its northeastern margin of 1,200 to 1,800 feet. From this gently undulating summit it descends gradually south and southwest to its margin against the older rocks to the south and to the Pacific coast. The central portion of the plateau has been but little modified by erosion, and probably preserves very nearly its original constructional form. This is due largely to the porous nature of the volcanic ash of which the surface is composed. The rain waters sink into the ground before they have an opportunity to collect into sufficient volume to effect any modification of the surface, except where the original slopes were very steep. A belt along the coast, however, has been rather deeply dissected by stream channels, where the smaller intermittent tributaries are collected into permanent trunk streams and where the plateau has a decided seaward slope. Toward the north and northeast the plateau is terminated by a somewhat abrupt escarpment, which separates it from the lower plain of Leon and from the plain lying between lakes Managua and Nicaragua. These lower plains have precisely the same origin as the Jinotepe plateau, and it is quite possible that at one time the lower and higher plains may have been continuous, but were subsequently separated by a depression of the region to the northeast. In other words, the escarpment which limits the Jinotepe plateau to the north and east may possibly mark the line of a rather recent fault. The escarpment has been deeply scored by stream channels, so that it does not now have the characteristic form of a recent fault scarp, but the character of the materials of which it is composed is such that it would be rapidly modified, and so retain its original form but a short time.

CLIMATE

GENERAL CHARACTER

The climatic conditions prevailing in this region have so direct a bearing on its geology and physiography that a brief statement of the more important characteristics of the climate is essential. Lying only 10 degrees north of the equator, the climate of the region is tropical, frost being entirely unknown. Furthermore, since it forms a narrow belt between two oceans, its climate is also insular, the annual range of temperature being very much smaller than all continental areas experience.

AMOUNT AND DISTRIBUTION OF RAINFALL

Throughout the greater part of the year the trade winds prevail with fairly constant direction and force. These winds are probably deflected slightly to the north by the high volcanic range of Costa Rica, and to the south by the mountains of central and northern Nicaragua. The low gap across the isthmus constituting the Nicaraguan depression thus receives considerably more wind than would be due to the normal trades. It is probably this congestion of the air currents that causes the exceptional precipitation of this region. Coming from the warm Caribbean sea, the trade winds are saturated with moisture, and, as they strike the slightly elevated land forming the isthmus, the precipitation is there very abundant. Within the zone of maximum precipitation, which embraces the coastal plain and the adjacent hills, forming a belt from 50 to 100 miles wide, the annual rainfall reaches nearly 300 inches. Beyond this belt, at increasing distances from the Caribbean coast, it decreases very rapidly, and in the western part of the region the annual rainfall is less than a third of that on the eastern coast.

More important, however, than the absolute amount of rainfall is its distribution throughout the year. The isthmus may be divided into two distinct and well marked subdivisions by a line coinciding approximately with the present divide between lake and Caribbean drainage and crossing the San Juan near the point where that river leaves the lake. In the eastern division the rain is distributed with tolerable uniformity throughout the entire year. There are some years in which little rain falls for a period of three or four weeks in August and September, but this scarcely constitutes a dry season. In the western division, on the other hand, there is a distinct dry season of five or six months, in which there is practically no rainfall. The rain begins about the middle of May, when the trade winds become less constant, and an occasional storm comes from the northwest.

PHYSIOGRAPHIC EFFECTS

Eastern division.—These climatic differences between the eastern and western portions of the region give rise directly to very striking differences in vegetation, and, either directly or indirectly, to differences in the appearance and structure of the soils, in the topographic forms of the land surface, and in the effectiveness of various physiographic processes.

The eastern division, in which the rain is distributed with tolerable uniformity throughout the year, is covered with a dense tropical forest. The only breaks in this forest are the stream channels and the open lagoons, or those so recently silted up that the soil is not sufficiently firm to support large trees. Throughout this region there are no human habitations, except in the few small towns along the coast and an occasional hut in a clearing on the banks of the rivers. There are no roads or other means of intercourse except by way of the streams.

The most directly apparent effect of the forest is to protect the land surface from erosion. The falling rain is intercepted by the canopy of foliage, and filters down gradually to the surface, where the smaller vegetation consists largely of palms, whose broad leaves afford a still further protection, so that the soil never receives the direct impact of the raindrops. Since there are no forest fires, the surface is more or less perfectly covered with forest litter, which acts as a further protective covering to the soil.

The character of the soil will be described more fully in treating of the regolith, but it may be stated here that the surface of this eastern division, wherever it rises above the level floodplains of the streams, is composed of a tenacious red clay. This clay never becomes dry enough to be intersected by shrinkage cracks, and is, of course, never loosened by the action of frost. Although it is penetrated by roots and to some extent by the burrows of insects, it nevertheless resists degradation to a remarkable degree. It was often observed that during a heavy rainfall the water flowing from the steep hillsides would be scarcely at all discolored by sediment.

After a careful study of the region it was concluded that the absence of frost more than counterbalances the enormous rainfall, and that degradation of the surface is, on the whole, slower than in temperate regions, where the rainfall is less than a quarter of that in Nicaragua, but where the surface soil is thoroughly loosened by the action of frost.

Many of the small brooks which carry water throughout the year and have very steep gradient flow in shallow channels cut in this clay. The clay often forms cascades, and appears to offer more resistance to corrasion than many varieties of rock. Although the hill slopes are steep, they are comparatively smooth, not deeply gullied, as is usually the case in temperate regions, and it is only after the water has collected in considerable volume that it is able to lower its channel through the clay to the underlying rock.

A further effect of the vegetation, and hence indirectly of the climate, is that many of the streams are filled with an abundant growth of vegetation, by which their current is checked and their effectiveness as an eroding agent correspondingly reduced.

The decay of vegetable matter is so rapid that there are no considerable accumulations of such matter either in the forest generally or in the lagoons and swamps. In boring through the alluvial floodplains, many of which have once been open lagoons, while an occasional log was encountered, nothing was found in the nature of peat, and the silt contains only a relatively small proportion of finely comminuted organic matter. On well drained surfaces, such as moderately steep hillsides, there is generally no humus layer. The red soil, practically free from incorporated organic matter, forms the surface, only in part covered by the forest litter.

Western division.—In the western division, particularly that portion of it lying west of the lake, the distribution of the rainfall produces a distinctly different type of vegetation. This region is characterized by open savannas, in which the trees are small and grow in isolated patches, the greater part of the surface being open and covered with grass or small bushes. These savannas are probably due to deforesting, in part by clearing for cultivation and grazing, and in part by fires. Wherever a forest covers the surface its character is entirely different from that in the eastern division. It has the thorny habit and scant foliage which characterizes the vegetation of a semi-arid region. The light is not cut off by the foliage of the higher trees, and hence the smaller herbaceous vegetation is much more abundant than in the eastern division. Fires prevail in the dry season, so that the forest litter does not accumulate, and at the beginning of the wet season, before the vegetation is renewed, the surface is entirely unprotected from the effects of the heavy rainfall which inaugurates that season.

Red soil is rarely seen west of the lake, the prevailing colors being blue, bluish gray, or black, and this is quite independent of the character of the rock from which it is derived, since the rocks are essentially the same as those which yield red soils in the eastern division. Toward the end of the dry season the surface is intersected by many deep cracks, often 2 or 3 inches wide and as many feet deep, which effectually destroy the coherence of the clay. This alternate saturation and baking of the soil therefore effects somewhat the same result as that accomplished elsewhere by frost. It also permits the incorporation of much organic matter with the upper portions of the soil, forming an exceptionally thick humus layer. From these and perhaps other conditions it results that the smaller rainfall of the western division is a very much more efficient agent of erosion than the greater rainfall of the eastern division.

The effect of these climatic conditions is seen in the topography which characterizes the region west of the lake. The hills are extremely steep and deeply gullied. At the mouth of each ravine there is an alluvial cone, showing that a heavy load of coarse and fine detritus is moved by the occasional flood which the ravine carries.

The depth of the residual material, the regolith, is also very much less on the west side than it is on the east. This is doubtless due in part to the fact that the conditions of rock weathering are less favorable in the former than in the latter region, but it is also due in part to the more favorable conditions under which the agents of degradation act. Both of these factors, however, are directly dependent on climate.

Another factor which on the west side may be effective in modifying topographic forms is wind erosion. During the dry season, when the protecting vegetation has been removed by forest fires, the steady force of the trade winds raises clouds of dust, and the total amount of transportation effected by this agency must be very considerable. The effects are most noticeable on the lake and ocean beaches, where the sand is driven with great force and piled up in dunes. Roads on which there is sufficient travel to keep down the vegetation are usually sunk below the surface of the adjacent country. The track is often bordered by a vertical bank from 5 to 15 feet high, and a part of this erosion is doubtless due to wind action.

Rock Formations

CONDITIONS FOR STUDY

The geology of the region under consideration has been examined in detail only in the vicinity of the route of the proposed canal. Even where studied most carefully, the relations of the various rock formations are extremely obscure. This obscurity arises chiefly from the nature of the exposures which must be depended on in making out these relations. East of the lake, rock exposures are very infrequent, and it is practically impossible from them alone to determine the relations of the various rock formations. The vegetation is so abundant that no distant views can be obtained, and the information which can usually be derived from a broad study of the topography is entirely wanting. The extreme depths to which the rocks are decayed and the uniform mantle of red clay which covers their outcrops effectually conceal their distribution and relations. The larger streams, as already explained, are chiefly flowing in old valleys which they are now silting up. Since they are not corrading their beds, their channels furnish exposures of materials other than alluvial only where they happen to impinge on the adjoining

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APPROXIMATELY ON THE LINE OF THE
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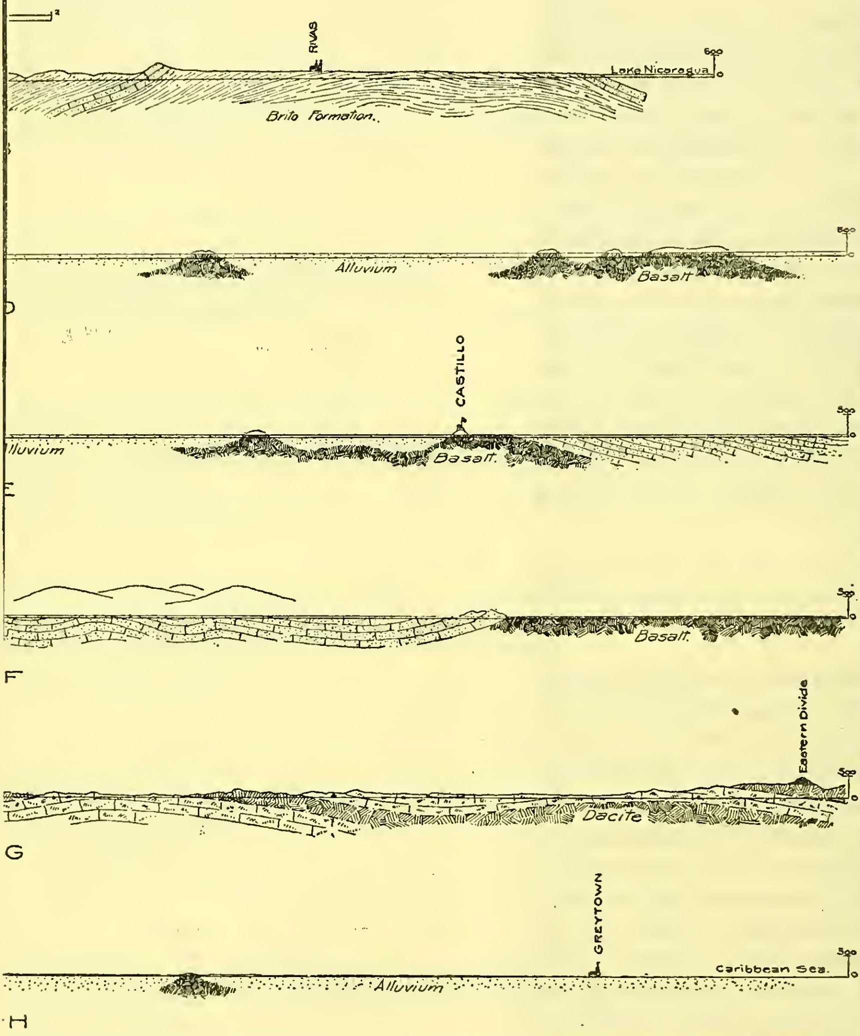


BEAN SEA TO THE PACIFIC OCEAN

hills in their broad meanders. The only exception to this general statement is the San Juan river between Castillo and Machuca. The conditions west of lake Nicaragua are somewhat more favorable. The vegetation is not so abundant, and the removal of the residual matter has more nearly kept pace with the rock decay; also the slopes are more abrupt, and most of the streams are corrading their channels, except in the lower portions of their valleys.

CLASSIFICATION OF THE ROCKS

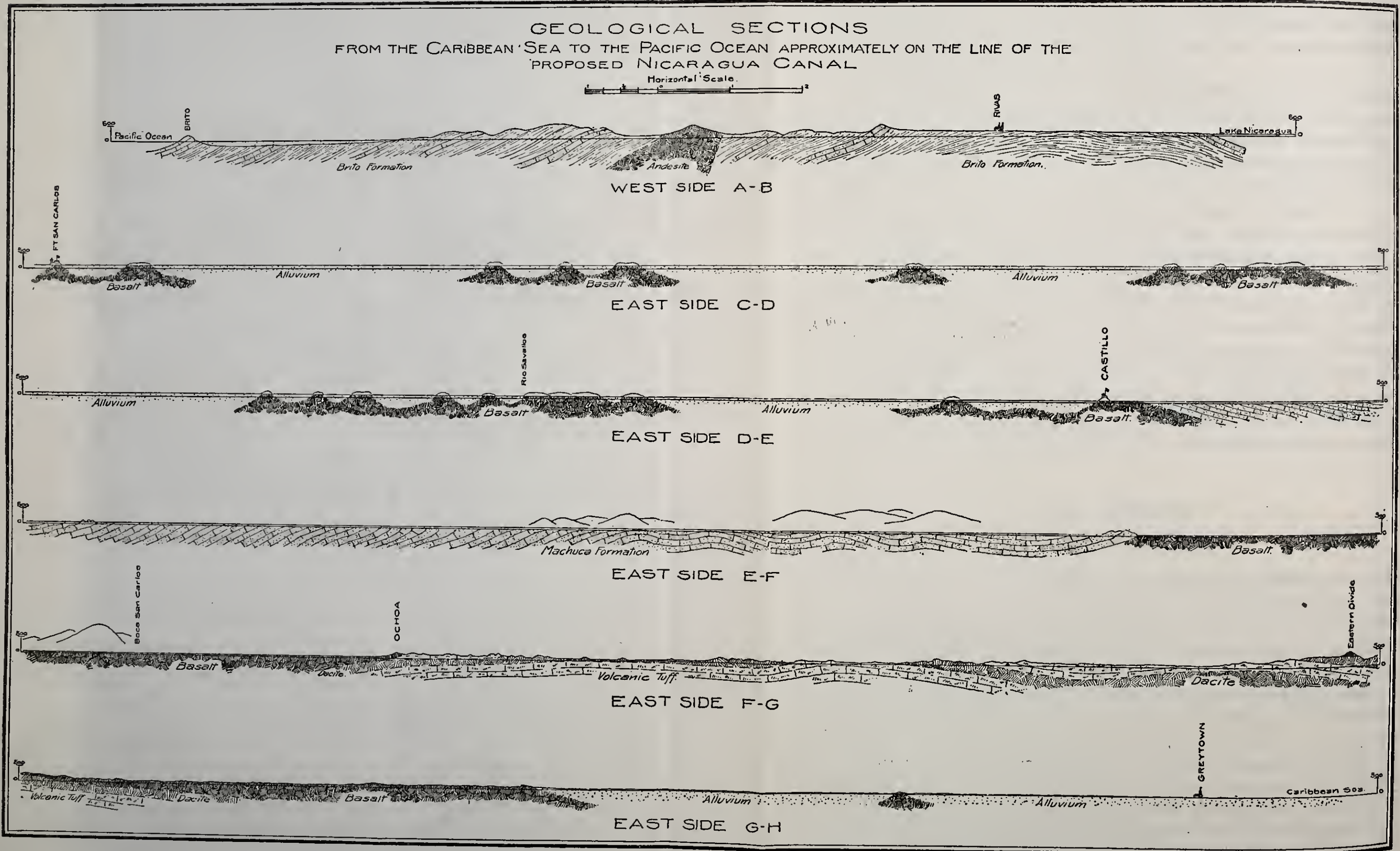
The rocks of the region are placed in two groups—Tertiary and post-Tertiary. Each includes both igneous and sedimentary formations. No rocks certainly older than the Tertiary occur along the line of the canal, although such have been reported from northern Nicaragua and also from central Costa Rica. The Tertiary sedimentary formations include the Brito and Machuca.

BRITO FORMATION

Distribution.—With the exception of a few areas of intrusive igneous rocks, the strip of land between lake Nicaragua and the Pacific is occupied entirely by the Brito sandstone. It extends from the Sapoa river to a point opposite the island of Zapatera. Remnants of the formation are also found along the lake shore to the southeast of Sapoa, and its present outcrops may extend continuously eastward to the area occupied by the Machuca sandstone. To the southward the formation is probably covered by the recent lavas of the Costa Rican volcanoes. It also probably extends some distance to the northwest of Zapatera, where it is covered by the recent tuffs which form the Jinotepe plateau.

Lithologic character.—The formation presents considerable variety in its lithological composition, but it has not yet been sufficiently studied to permit of its subdivision, even if this may be eventually possible. Much the larger mass of the formation consists of somewhat calcareous non-fissile shale. When fresh this is bluish gray and weathers to a yellowish or brownish color.

Distributed through the shale are numerous beds of sandstone. These are also somewhat calcareous and doubtless contain a considerable proportion of volcanic ash. The sandstone beds vary in thickness from a few inches to two or three feet, and occur singly or in groups. The latter are sufficiently heavy to materially affect the topography in some places. These sandstones, like the shales, are blue when entirely fresh, but are always weathered at the surface to some shade of yellow or brown. The hills immediately west of Rivas, rising abruptly above the Rivas plain, are due chiefly to the presence of these resistant sandstones. They occur



GEOLOGICAL SECTIONS IN NICARAGUA FROM THE CARIBBEAN SEA TO THE PACIFIC OCEAN

most abundantly, however, near the Pacific coast, and are well exposed in the headland northwest of the Rio Grande valley at Brito. The beds here have a general, though somewhat variable, dip to the southwest; hence the higher portions of the formation make the cliffs along the Pacific. This seems also to be its most variable portion.

In addition to the shales which constitute its greatest bulk to the eastward, it here contains also beds of sandstone, conglomerate, and coarse volcanic breccia on the one hand, and on the other marly beds and lenses of pure limestone. Forming a part of the headland south of Brito is a bed of limestone something over 100 feet in thickness. Small outcrops of this bed, or one very similar, have been noted at several other localities to the eastward in the divide hills. Its limited extent is due in part to erosion, since the dip of the bed would carry it above the tops of most of the hills to the eastward, but it is doubtful if its original extension was very great. Several of the limestone outcrops noted are probably small lenses in the shale and not connected with the more continuous bed at Brito. A portion of this limestone has a peculiar concretionary structure, some of the concretions attaining a diameter of an inch and a half while other portions of the bed are oolitic.

Immediately west of this exposure of limestone, forming a group of islets nearly covered by high tide, is a very coarse volcanic conglomerate or breccia. The larger fragments are a foot or more in diameter and quite angular, and from this extreme they grade downward to small pebbles, some of which are well rounded. The present relations indicate that the conglomerate is the stratigraphical equivalent of the limestone, replacing it within a few yards. In some places the two rocks are seen to merge, the limestone containing numerous angular fragments of volcanic rock. At other points along the coast both north and south of Brito similar conglomerates occur. Their bedding is extremely irregular, and they afford evidence of having been formed rapidly and near the source from which their constituents were derived. While it is possible that the source of this material may have been to the eastward, it seems much more likely that it came from volcanic vents to the southwest—from volcanoes which have been entirely removed by the waves of the Pacific.

Although their connection has not been continuously traced, it is assumed that the sedimentary rocks found at various points along the southern margin of the lake east of Sapoa belong to the Brito formation. This region was examined by coasting along the lake shore, so that it was chiefly the rocks forming the projecting headlands which were observed. These consist almost entirely of sandstones very similar in appearance to the sandstones found interbedded with the Brito shales, and also conglomerates and breccias similar to those occurring at various points along the Pacific coast.

Structure.—The Brito formation, wherever observed, was found to be intersected by numerous joint planes. In some places these occur as two well developed sets of approximately parallel planes, which intersect each other nearly at right angles. In others the joint planes are very numerous and irregular, cutting the beds in all directions. The latter form is less common and appears to be confined to rather narrow zones where shearing and faulting has probably taken place. The frequency of the joint planes varies with the thickness of the beds. The rhomboidal blocks into which the beds of shale and sandstone are broken usually have diameters approximately equal—that is, the more massive the original beds the farther apart are the intersecting joint planes. These joints have permitted the percolations of surface waters to great depths and have facilitated the deep weathering which is generally observed. The weathering proceeding outward from the joints has resulted in the formation of concentric layers about a core, which coincides with the center of the original rhomboidal block. The resulting rounded blocks in some places give the appearance of a rude rubble wall. In the vicinity of Las Lajas the horizontal sandstone beds have been lain bare by the action of the waves, and where the rhomboidal blocks produced by jointing have been rounded by concentric weathering the appearance is that of a cobble pavement.

The Brito formation has suffered only a moderate amount of disturbance since its beds were deposited. Where its rocks are best exposed along the Pacific coast, numerous small faults are observed, the displacement in most cases being but a few inches. The inclination of the beds is generally under 20 degrees, though in a few localities the disturbance has been much greater and the dips increase up to the vertical. Neglecting these minor irregularities, the dominant structure is a broad anticline whose axis extends in a northwest-southeast direction approximately parallel with the Pacific and lake shores and a short distance southwest of the latter, where the beds are approximately horizontal. The greater portion of the region between the lake and the Pacific, therefore, is occupied by the western limb of the anticline and has prevailing southwest dips. From San Jorge to Lajas the dips are somewhat variable, but generally to the northeast. The greater part of the eastern limb of the anticline is covered by the lake. The numerous exposures of the Brito formation along the southern margin of the lake from the Sapoa to the Rio Orosi belong to this eastern limb of the anticline, and the beds have northeasterly dips of 5 to 30 degrees. The strike of these beds is not strictly parallel with that of the beds on the Pacific coast. They converge slightly toward the northwest, indicating a pitch of the anticline in that direction.

The exposures of the Brito formation are so infrequent and the dips are so variable that no satisfactory measure of the thickness of the formation can be obtained. Taking the observed dips between the Pacific coast and the lake shore, the thickness exposed is estimated at upward of 10,000 feet. This, of course, is not the total thickness of the formation, since the bottom is not exposed at the axis of the anticline; also, the formation has undoubtedly suffered an unknown but considerable diminution in thickness by erosion, and there are no data for determining the thickness of strata which have been removed from the highest beds now observed.

Age of the formation.—The greater part of the Brito formation is apparently barren of organic remains. The only locations at which fossils have been found are on or near the Pacific coast. This, however, may be due to the fact that the rock exposures are not elsewhere of such a character as to facilitate the discovery of fossils, and the latter may possibly be more generally distributed than present knowledge would indicate. The fossils are confined almost wholly to the limestones and marly beds. They consist of corals, molluscan and foraminiferal remains. The latter are especially abundant. The rather meager collections have been submitted to Dr Dall for determination. He pronounces them Oligocene, and probably identical with the foraminiferal beds described by Hill from the Caribbean coast at Panama. One of the most abundant forms is a small numulite, *Orbitoides*, probably *forbesei*, which is characteristic of the lower Oligocene. The molluscan remains were collected on the Pacific coast, about 75 miles northwest of Brito, in what was supposed to be a higher portion of the same formation. Dr Dall states that these have the upper Oligocene aspect, though there are not enough of them to be conclusive. He thus confirms the view entertained in the field, that successively higher beds in the Brito formation are exposed along the coast toward the northwest.

In addition to the fossils on which is based the above conclusion concerning the age of the Brito formation, it also contains rather abundant plant remains. They are in the form of driftwood and coal, but as yet no remains sufficiently well preserved for identification have been discovered.

Associated with the coarser sandstones are numerous blocks of wood, whose rounded forms suggest that they are fragments of drift which were incorporated with the sand and gravel while it was accumulating. In some cases they still contain a large proportion of their original carbon, and in others this has been more or less perfectly replaced by silica or iron pyrites. The coal occurs associated with the finer sediments, and, although a careful search was made, the thickest seam observed was under half an inch. While sufficient carbonaceous matter is sometimes disseminated through the shales to give them a black color, no indications were found pointing to the existence of workable coal deposits in the region examined.

Coal in workable quantity has been reported from the region southwest of the lake, between the lake shore and the Costa Rican volcanoes. The exact locality is on the Rio Hacienda, 12 miles from its mouth. It was not visited and no samples of the coal were seen, so that the report lacks verification. There appears to be no reason, however, why conditions favorable for coal accumulation should not have prevailed in some portions of this region during the deposition of the Brito beds.

MACHUCA FORMATION

Distribution.—The immediate margins of the San Juan valley from the lake eastward to Castillo are, so far as known, composed entirely of igneous rocks. From a point a few miles below Castillo to another midway between Machuca and the Boca San Carlos the rocks are largely sedimentary, although they contain some igneous rocks in the form of small dikes. These sedimentary rocks constitute the Machuca formation. Its present extent is known only in the immediate vicinity of the river. The region south of the upper San Juan, forming the lower valleys of the Frio and Poco Sol, is geologically unexplored. It is therefore possible that the Machuca formation may extend westward through this region and be nearly, if not quite, continuous with the outcrops of the Brito formation south of the lake. Until this connection is established, however, the original continuity of the two formations is a matter of doubt.

Lithologic character.—The rock exposures in this region to the eastward of Castillo are very much less satisfactory than those along the Pacific coast; hence the character of the Machuca formation is not so well known as is that of the Brito. Like the latter, it appears to consist chiefly of calcareous shales, with which sandstones are interbedded. The constituents of the rocks are largely igneous in their origin, but there are no coarse conglomerates or breccias such as occur in the Brito.

No pure limestones or distinctly marly beds have been discovered, although the examination of the formation has not been sufficiently exhaustive to enable one to say that such beds do not occur.

Structure.—The exposures are comparatively few in which the dip of the Machuca sandstones can be determined. At the Cano Bartola the dip is about 15 degrees and to the north. At Machuca it is 20 degrees and to the northwest. These dips suggest the presence of a synclinal basin, the southern end of which is crossed by the San Juan. They are not sufficient, however, to locate its axis. Although in general the dips are light, the formation has suffered considerable local disturbance. Breccias, probably due to faulting, have been observed at several points, the best example being the ledge which projects into the river opposite the mouth of the Machuca; also numerous sharp folds occur in the vicinity of Machuca. The same evidence of faulting and folding would probably be found elsewhere if the exposures were sufficiently abundant to render the structure determinable.

The rocks of the Machuca formation are generally found deeply weathered. The weathering is hastened by the igneous constituents which they contain, and the final product is a residual red clay, which is indistinguishable from the product of the decay of igneous rocks. Except for the fresh rock obtained beneath the residual mantle by means of the diamond drill, it would have been impossible to determine even approximately the limits of the sedimentary and igneous rocks. At some points, as at Machuca, the sandstone contains a very large proportion of iron pyrites, which by oxidation also tends to hasten its decay.

Nearly everywhere the beds are intersected by numerous joint planes, the only marked exception being the rather massive interbedded sandstones exposed on Machuca creek. Weathering has proceeded inward from the joints toward the centers of the rhomboidal blocks, producing concentric shells about a central nucleus exactly as in the Brito formation.

Age of the formation.—No fossils have yet been found in the Machuca formation which are sufficiently well preserved for specific determination. At Cruzita, one mile below Machuca, the core from the diamond-drill hole in the bed of the river contains numerous indistinct organic forms. The rock is described by Dr Ransome as an andesitic tuff containing fragments of limestone. The organic forms are revealed by the weathering of the rock with the removal of the soluble limestone, and they are also shown in the thin-section under the microscope. While they can not be identified they strongly suggest the forms which occur so abundantly in portions of the Brito formation. The beds in which they occur are evidently derived in large part from fresh volcanic tuff, though the latter was not so abundant as to prevent the growth of organisms in the sea in which it was being deposited.

In the absence of conclusive fossil evidence, therefore, the age of the Machuca formation, so far as it may be determined, rests on other and less satisfactory evidence. It is believed to be nearly or quite contemporaneous with the Brito formation—that is, Oligocene (Tertiary). The grounds on which this conclusion is based are briefly as follows: (1)

There is a general similarity in lithologic composition and appearance between the two formations. (2) Both have suffered about the same amount of deformation, elevation, and erosion since they were deposited. The value of this fact for correlation depends on the proximity of the areas which they occupy and the evidence that the recent geologic conditions have been similar in both. (3) Both formations bear about the same relation to a group of igneous rocks, which was in part contemporary with them and in part subsequently invaded their beds. The differences in composition of these intrusive rocks are not greater than differences in igneous rocks within the same area, which are known to be nearly or quite contemporaneous. (4) Finally, as pointed out above, it is quite possible and even probable that the two formations are nearly or quite continuous through the southern part of the upper San Juan valley.

In the vicinity of the Toro rapids, some distance westward from the present limit of the Machuca formation, a few siliceous boulders have been found which contain fossil remains. The original location of the beds from which these boulders are derived is not known, though they have probably not been transported a great distance. These fossils are unfortunately only casts. They have been examined by Dr Dall, who says they "are not determinable, but have the general look of a freshwater assembly." They are not regarded, however, as having any special bearing on the age of the Machuca, since it is by no means certain that they have been derived from that formation.

TERTIARY IGNEOUS ROCKS[*]

Location and general character.—As stated above, the beds of the Machuca formation occupy a broad belt, which crosses the valley of the San Juan, extending from a point a little below Castillo eastward some distance beyond Machuca. While this formation contains a considerable proportion of volcanic material and is intersected by numerous dikes, it contains no lava flows and no beds the constituents of which are exclusively of volcanic origin. In the remainder of the country between the lake and the Caribbean, wherever the underlying rocks or their residual products rise above the recent alluvium of the floodplains, the rocks are almost entirely of volcanic origin. They present a great variety in structure and appearance, varying through the extreme types of volcanic products from distinctly stratified beds of fine volcanic ash, through well rounded conglomerates, fine and coarse angular breccias,

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[*] The writer is indebted to Dr F. L. Ransome, of the U. S. Geological Survey, for a petrographic examination of the igneous rocks collected in Nicaragua and determination of the rock species.

surface lava flows, and intrusive masses of rather coarsely holocrystalline rock which did not reach the surface before cooling.

Massive igneous rocks.—The principal varieties of igneous rocks which are found between the lake and the Caribbean are *augite andesite*, *olivine basalt*, *hypersthene basalt*, and *dacite*. Of these four varieties the first three are very similar in appearance, and can not ordinarily be distinguished with certainty in the field. They are dark bluish gray to black in color, generally fine grained, but often containing certain minerals, as olivine and feldspar, which can be readily distinguished with the unaided eye. They are generally compact and heavy, though a well marked vesicular structure characterizes some portions of the basalt. The red clay which is the final product of their decay contains numerous residual boulders of the fresh rock covered with a thin ochreous crust.

The dacite is light gray in color, and is made up of abundant quartz and feldspar crystals embedded in a fine grained or glassy, gray groundmass. It is lighter than the trap rocks, and is considerably softer even when entirely unweathered. The dacite contains numerous fragments of darker basic rocks. It doubtless reached its present position as a lava flow, and these inclusions are fragments of the underlying rock which were picked up and incorporated in the molten mass during its passage through the lower formations to the surface. Many of them are a soft greenish rock exactly like the tuff on which the dacite rests. The presence of these included fragments of a different rock is doubtless the reason the dacite was called conglomerate in the Canal company's eastern divide sections. Of the fragmental igneous rocks two classes may be made, according as their igneous or sedimentary characteristics are the more prominent. In the first class are included the tuffs which form the western portion of the eastern divide, passing under the dacite at an angle of about 5 degrees. This tuff is related to a basic lava, either andesite or basalt. It has a dark greenish color and very fine grain. It is soft and talcose, and on exposure to the air the cores generally crumble into small fragments. While this tuff owes its kaolin-like character to the decomposition of a basic glass, it was probably never a hard rock. The pressure to which it has been subjected since its deposition has apparently not been sufficient to produce complete induration.

The extent to which these rocks have weathered has been already pointed out, but may be referred to again in explanation of the difficulty which has been experienced in determining the relations of the various members of the volcanic formations. All weather to a red clay, and exposures which afford any indication of the original character of the underlying rock are extremely infrequent. The chief reliance must be placed on the occasional residual boulders, on the presence or absence of quartz grains in the clay, and on the occasional cut banks along the streams. The large scale sections of the proposed damsites indicate the complexity of the relations between the various volcanic formations and the hopelessness of attempting to work out these relations from surface indications alone without the aid of sections derived from drilling. For the reasons given above it is practically impossible to map the surface outcrops of these various rock varieties. Their distribution can only be indicated in a general way.

The rock forming the hill on which San Carlos is located consists of augite-andesite. This extends eastward down the river to the Rio Melchorita, forming the hills which rise above the level alluvial plains. At Palo de Arco occurs olivine basalt, and this rock continues eastward a short distance beyond Castillo. At the Sabalos it presents an amygdaloidal phase, and in the hill near the mouth of the Santa Cruz it consists of a very coarse breccia. The high hills at the junction of the San Carlos with the San Juan consist of hypersthene basalt. This is a holocrystalline rock, and one which probably cooled at some distance below the surface. It may possibly mark the center of eruption from which lavas in the surrounding region, which have a similar composition but less perfect crystalline structure, were derived. A similar but less crystalline rock also occurs in the hills on the north side of the San Juan river. To the eastward, at Ochoa, the hypersthene basalt occurs south of the river, while the rocks at the river bank on both sides and extending to the northward are olivine basalts. This olivine basalt extends eastward beyond the San Francisco hills. At the Tamborgrande it is replaced for a short distance by dacite; then in the Tamborcito hills by hypersthene basalt, but again comes in in the Sarapiqui hills, and thence extends east, forming all of the hills which border the lower portion of the San Juan river, and also those about Silico lake. The dacite, while it does not reach the surface at Ochoa, was encountered there in boring. It was also found at lower Ochoa, beneath a bed of volcanic tuff or breccia and some unconsolidated sediments. It comes to the surface at Tamborgrande, and it probably continues north in the high ridge connecting the Tamborgrande hills with the eastern divide. It forms the surface through the higher portion of the eastern divide, overlying andesitic tuffs and passing under basalt.

Fragmental igneous rocks.—Since the closely related fragmental rocks, both the bedded tuffs and the conglomerates, do not weather in such a way as to furnish residual boulders, their presence is much more difficult to detect. From the character of the exposures in the bluffs along the San Juan river, and from the results of the drill sections, it seems probable, however, that the bulk of these fragmental rocks is as great or greater than that of the massive rocks. About 4 miles above the Boca San Carlos these beds are exposed in a high bluff on the north bank of the river. There is shown a considerable diversity in the character of the material, varying from the finest tuff to coarse rounded conglomerate. All parts of the beds are equally weathered, forming a tough clay quite free from grit. The different beds vary considerably in color, although the prevailing colors consist of various shades of red and brown. The planes of stratification between the different beds are not sharply marked, and the indications are that the deposit was made rather rapidly and in the presence of strong currents. Similar exposures of thoroughly decayed sedimentary beds occur in the river bluffs at various points between Ochoa and the mouth of the San Francisco.

It is probable that during the extrusion of the volcanic rocks in this region numerous bodies of water were formed by the interruption of drainage lines by the lava flows. In these bodies of standing water the finer tuffs were accumulated with considerable regularity in their planes of stratification. Forests were present on the adjoining shores and much vegetable matter was accumulated along with these silts. There thus resulted deposits of considerable depth, such as those encountered at Lower Ochoa. These were subsequently covered by lavas or deposits of fragmental material, but have never been buried sufficiently deep to bring about their complete consolidation.

In some places conditions were favorable for the deposition of calcareous material. In the section at the San Francisco a bed of very fine grained earthy limestone about 3 feet in thickness was encountered with fine tuff above and below. The limestone was perhaps originally a calcareous mud which has been thoroughly solidified and is now comparatively hard. The adjacent tuffs, both above and below, may have been solidified at one time, but are now soft and talcose. No traces of organisms can be detected in this limestone, and it may have been precipitated from solution without the intervention of life. In the railroad cut near Silico lake there occurs a bed of clay enclosing water-worn pebbles and numerous fragments of wood which is immediately overlain by a flow of basaltic lava. This clay was doubtless alluvial or accumulated in a lake and has probably not been buried to a sufficient depth to produce consolidation.

The beds of lava and volcanic tuff above described have been but little changed from the position in which they were originally deposited. Wherever bedding planes can be detected in the stratified tuffs they are practically horizontal. The planes separating lava flows generally have a decided original inclination, and this may be increased or diminished by subsequent tilting. In the sections of the upper and lower Ochoa damsites (plate 31) the planes separating the several formations have a slight dip to the northeast. The same thing is observed in the sections of the San Francisco embankment line and of the Eastern divide. In so far as these dips are due to deformation, they suggest the presence of a low anticline to the east of the Machuca basin, its axis approximately parallel with the Caribbean coast and crossing the San Juan near the Boca San Carlos. For reasons given above the structure of these igneous formations, as well as of the Machuca sandstone shown on the geological sections (plate 32), rests on a very few observations and should not be accepted with too great confidence.

RECENT ALLUVIAL FORMATIONS

The post-Tertiary formations of the region include the recent deposits which make up the floodplains of the rivers and the deltaplains about their mouths, together with the products of the recent volcanic activity.

The character of the alluvium has been somewhat fully described on a previous page and requires but little further mention. It varies in character with the local conditions under which it is deposited and with the character of the rocks from which it is derived. On the west side, filling the valley of the Rio Grande, it consists of fine brown sand and clay, derived from the decay chiefly of the sandstones of the Brito formation. In some places it contains enough calcareous cement, which has been deposited by infiltration from above, to give the alluvium a fair degree of coherence.

In the valley of the San Juan there is considerably wider diversity in the character of the alluvium. In the upper portion of the valley it consists of fine blue clay interbedded with fine blue and brown sand. The sand occurs chiefly in the river channel and is the residuum which the sluggish current of the river has been unable to transport. It is probable that but little sand would be encountered in the alluvium at any considerable distance from the present channel.

In the lower portion of the valley the alluvium in the immediate vicinity of the river contains considerable black sand, such as it is at present transporting in great volume. This occurs either disseminated through the finer silt which is derived from the decay of rocks in the adjoining region or it occurs as distinct layers interstratified with the clay. The presence of a considerable proportion of sand in the silt renders it much firmer than when the latter consists chiefly of clay. The sand does not extend to any great distance from the present river channel, and hence the silt becomes less stable with increasing distance from the river.

The material which fills the tributary valleys, such as the Danta, the San Francisco, the Cureño, and the Tamborcito, is a fine silt, generally quite free from grit, with a blue color, and containing abundant fragments of wood and leaves. When this material is thoroughly drained it becomes fairly compact, as shown in the vertical banks of most of the streams, but at some distance from these streams, where the drainage is imperfect, it is quite soft to a great depth.

This alluvial silt or mud when first exposed sometimes has a brilliant blue color, which quickly changes to a yellowish brown on exposure to the air. The change in the color takes place at the exposed surfaces within a few minutes.

The material forming the deltaplain of the San Juan is similar to that composing its floodplains. The black sand is carried out to sea and transported along the shore by littoral currents and thrown up to some distance above tidelevel by the waves, so that within a belt two or three miles broad along the coast the surface is composed chiefly of black sand, with a small amount of vegetable mold. The fine silt increases in thickness from a feather-edge at its outer margin at a rate somewhat greater than the eastward slope of the deltaplain.

It is probable that the delta has always been fringed by a belt of sand which never rose more than a few feet above sealevel. The region, however, has been sinking while the delta was forming. As the delta grew by accretions of sand to its outer margin, the corresponding growth on its surface was made by the fine silt deposited from the flood waters of the rivers. The plane separating the sand from the overlying silt thus appears to have a gentle landward inclination, being slightly above sealevel at the present coast and some distance below sealevel toward its inner margin.

RECENT VOLCANIC ROCKS

The vulcanism which gave rise to the igneous rocks associated with the Tertiary sediments appears to have become entirely extinct in this region, and doubtless a long interval elapsed in which it was free from any manifestations of volcanic activity. In comparatively recent times the vulcanism was renewed and its products form the Costa Rican and Nicaraguan volcanic ranges, which have already been described. Its products also form the Jinotepe plateau and the plain of Leon, which extend northwest from the Lakes to the Pacific.

In mineralogic composition these recent volcanic products consist very largely of hypersthene-andesite. The last eruption from Masaya was a basaltic lava, and a comparatively recent lava flow from Ometepe is also a basalt. With these two exceptions the recent activity, so far as observed, has given rise only to andesitic lavas and tuffs. The cone of Ometepe consists largely of lapili, with occasional interlaminated lava flows. The lapili consist in about equal parts of black or gray pumice and of black glassy rock, which has been thoroughly shattered and ground up by explosive eruptions. The tuffs from this volcano, which have been carried to a considerable distance from the center of eruption chiefly by wind, are composed more largely of tuffaceous material.

The materials erupted from the other volcanic centers forming the various peaks of the Nicaraguan range appear to be similar in composition to those found in Ometepe. The Jinotepe plateau is composed largely, if not altogether, of volcanic tuffs, which probably reached their present position in the form of a more or less fluid mud. This mud becomes solidified, but never sufficiently so to form hard rock. It is quarried in many places and used as a building stone. It can be readily cut out with a pick, but becomes somewhat harder on exposure to the air. The rock fragments which constituted this tuff vary widely in size, from large boulders several feet in diameter to the finest dust. They are all angular, and in this respect they differ from the volcanic conglomerates associated with the Tertiary rocks of the San Juan valley. A further difference is the almost complete absence of stratification and sorting of the rock constituents. This tuff appears to have been sufficiently fluid to flow on rather low slopes, and the present southward and westward slopes of the Jinotepe plateau are probably the original constructional slopes.

In the vicinity of Managua planes separating successive mud flows intersect the rock and are utilized in quarrying. In these quarries human tracks have been found in the rock, where they were made while it was still in the form of mud. They prove the recency of the tuffs and indicate something as to its physical condition when first deposited. At the margin of this plateau the tuff is found filling the valleys in the older formations and smoothing out the former irregularities of the topography. In many cases the present streams have in part reëxcavated the old valleys, though not to their original width.

The vertical cliffs surrounding the caldera lakes, Apoya and Masaya, display the underlying structure of this plateau near the centers from which its material was derived. These cliffs are composed of alternating layers of tuff and solid lava flows. It is impossible to say how far from the centers of eruption these lava flows extend, but the distance is probably not very great. Near the centers of eruption the character of the tuff is somewhat different from that at greater distances. It is less homogeneous in character and frequently consists of sharply defined alternating tuff beds which differ widely in appearance. In the bluffs surrounding lake Apoya this is well shown. Numerous distinct bands of white pumice occur interbedded with dark lapili and fragmental rocks, and these in turn are interbedded with the lava flows.

Rock Decay

IMPORTANCE OF THE SUBJECT

One of the features which first impresses the geologist or the engineer in Nicaragua is the extent to which the surface rocks are weathered. This feature is common to all tropical regions, at least to those in which there is an abundant rainfall. While the extent of rock weathering has an important bearing on the geology of the country, and thus a high degree of scientific interest, it is a fact of prime importance to the engineer in planning any structures in this region. It enters directly into the cost of excavation and also into the cost and permanence of foundations for all heavy structures.

CONDITIONS FAVORING ROCK DECAY

General discussion of the subject.—It has been shown by various investigators that the conditions most favorable to rapid rock decay, and hence to the accumulation of an extensive mantle of residual materials, are high temperature and abundant moisture. These conditions are only indirectly responsible for a large part of the rapid rock decay which always accompanies them. They are also the conditions on which the rapid growth and decay of a luxuriant vegetation depends, and it is the latter process which is chiefly instrumental in hastening the process of rock weathering.

It is manifest that heat alone, without moisture, does not give rise to conditions which favor rock decay, for it is a common observation in desert regions, where the temperatures reach the maximum, that the rocks are disintegrated to a limited depth by the alternate expansion and contraction due to changes in temperature, but that rock decay is practically absent. On the other hand, abundant moisture and continuous low temperature do not give conditions favorable for rock decay, since these conditions favor the accumulation of ice and snow. Glaciers are effective instruments for transportation of rock debris and to a limited extent are efficient as eroding agents, but practically no rock weathering goes on in their presence.

Even where the moisture is abundant and the temperature is sufficiently high for the growth of an abundant vegetation, unless the conditions are also favorable for the decay of that vegetation they are not favorable for rock weathering. This is seen in the extremely luxuriant forests of the North Pacific coast, where the successive generations of forests grow on the remains of their predecessors. The conditions are here favorable for the preservation of vegetable remains in the form of peat, and rock decay is practically absent. It appears, therefore, that an essential condition for rapid rock weathering is the rapid decay of abundant vegetable matter, and this leads to the conclusion that the most efficient factor in the weathering process is the presence of the complex organic acids which are derived from the decay of vegetation.

Effect of chemical composition.—The depth to which the rock decay has gone and the character of the products depends in a considerable measure on the chemical composition of the rock, on its original structure, and on the subsequent alterations which it has undergone, such as fracturing in the process of consolidation or by subsequent dynamic disturbances.

But few rocks are found in this region which are not either wholly or in large part composed of material of volcanic origin; hence their chemical composition does not present so wide a range as is usually found among sedimentary and igneous rocks. A few are apparently the products of thermal springs, and the composition of these is perhaps the best suited of any to resist the process of rock decay. Examples of rocks of this origin are found in the small hill opposite San Francisco, a short distance east of the lake, and also at Chorrera, on the Aguas Muertas. These are composed chiefly of silica, which is the mineral least acted on by the processes to which rock decay is chiefly due.

The Machuca sandstone, as already explained, contains a large proportion of feldspathic minerals, as well as iron sulphide and carbonate of lime; hence it is peculiarly susceptible to hydration, oxidation, and solution.

The igneous rocks belong to the basic and intermediate classes, and hence contain a large proportion of the lime-soda feldspars and the ferro-magnesium minerals. Both of these groups of minerals are especially liable to alteration. Quartz, on the other hand, is relatively scarce. There are in the region no quartzites and argillites, the two classes of rocks which are especially indifferent to the action of the weathering processes.

Certain beds associated with the lavas are composed of fine volcanic ash, in which the constituent particles had never acquired a crystalline structure, but were entirely glassy. These are pèrhaps the most readily altered rocks in the region, and wherever they have been encountered, even as in the eastern division, at very great depths beneath the thick sheet of dacite, they are found in the form of a soft, soapy or talcose rock.

The rocks of the Brito formation contain a much smaller proportion of igneous constituents than any of those in the eastern division; hence they are in a measure free from this source of weakness. They contain, however, a large proportion of lime carbonate, and in them the weathering process consists chiefly in the solution and leaching out of this cementing material. In most of these rocks the lime forms so small a proportion of the entire mass that the bulk is not diminished or the structure altered by its removal. The rock merely changes in color from bluish gray to brown or yellow, and at the same time it becomes soft and porous.

Effect of original structure.—The original structure of many of the rocks is such as to facilitate weathering to a considerable degree. This is especially true of the basalts, which are largely composed of surface lava flows and have the vesicular structure which is characteristic of such flows.

In many cases it is observed that the degree of weathering in the case of basalts varies directly with the extent of the vesicular structure. The upper and lower surfaces of the flows which were rapidly cooled by contact with the underlying rocks and by exposure to the air contain more or less abundant gas bubbles, while their central portions are relatively compact. In such cases it is found that the vesicular portions are thoroughly weathered, while the interior compact portion contains large boulders of fresh rock or continuous beds of the same. The dacite, which, so far as observed, never has the vesicular structure of the basalt, does not show these striking differences in the degree to which its different portions have weathered.

The depth of weathering in the volcanic sandstones and conglomerates naturally depends largely on the original structure of their constituents, which shows considerable variation. Thus the conglomerate encountered at upper Ochoa is composed chiefly of pebbles of compact, fine grained basalt, and is weathered only to a moderate depth. A conglomerate was encountered at lower Ochoa similar to the above, except that its constituent pebbles are largely composed of vesicular or pumicious basalt. This difference in the composition of the pebbles is accompanied by a corresponding difference in the depth of weathering, which has extended to a very great depth in case of the latter rock.

Effect of secondary structures.—A third important factor in determining the depth to which rock decay has gone is the extent to which the rocks have been affected by dynamic agencies with the production of secondary structures, such as folds, faults, and joint planes. Of these effects jointing is perhaps the most important. It pervades nearly all the rocks of the region, both igneous and sedimentary. The joints which intersect the igneous rocks are perhaps largely due to shrinkage on cooling. The regular prismatic jointing common in basaltic lava flows has not been observed in this region. In its stead is a system of more or less regular joints which divides the rock into large rhomboidal blocks. The less basic rocks, such as the dacite and the volcanic conglomerates, are nearly or quite free from these joints, and the manner in which they weather is therefore quite different from that of the basalt.

The sedimentary formations are generally very deeply fractured. In these the joints are doubtless due to the action of dynamic forces, which, while they have not greatly changed the original position of the beds, have been sufficient to thoroughly shatter them to great depths. Only a few of the more massive beds of sandstone have in some measure escaped this general fracturing. Its effect is most pronounced in the less massive portions of the Brito formation. At the surface the joints have been enlarged by the weathering process, and the rock consists of a loose mass of small fragments. This condition prevails to a depth of more than 100 feet from the surface, as shown by the boring at La Flor. In some cases it was observed that the cracks which intersected the rocks had subsequently been healed up by the deposition of calcite. This, however, is not general at ordinary depths.

A direct consequence of the presence of these cracks intersecting the rocks is the development of secondary concentric structures. The cracks permit the percolation to great depths of surface waters bearing the agents which are most active in rock decay. The weathering proceeds outward from these joints with the production of successive concentric layers about a central nucleus. The concentric structures which have already been described were thus produced.

ROCK DECAY IN THE EASTERN DIVISION

As has been already pointed out, there is a marked difference in the distribution of the rainfall on opposite sides of the isthmus, with a corresponding difference in the character of the vegetation and in the extent and products of rock decay. It will be necessary, therefore, to consider the process and the products in the two divisions of the isthmus separately.

The eastern division is characterized by a heavy rainfall, so distributed throughout the year that there is no well marked dry season; hence the surface soil is never permitted to become dry and the forest litter is never removed by fires. The entire surface is covered with a dense mantle of vegetation. This consists of a heavy forest growth, except where the land surface has been so recently reclaimed from swamps and lagoons that it has not yet been invaded by the forest, or that its surface is not sufficiently firm to support forest trees. Even where the forest does not extend, the smaller vegetation is extremely dense and the surface is even more effectually protected than under the forest. It may be stated in general, however, that all of the land which rises above the margins of the extensive floodplains and the silt-filled valleys—that is, all which is underlain by rocks older than the recent silt—is forest clad. The canopy of foliage formed by the treetops is so perfect that much of the light and all of the direct sunlight is intercepted; hence the smaller vegetation at the surface is not exceptionally luxuriant and only partially covers the surface.

The forest trees of this region are nearly all deciduous, but the season of shedding their foliage is different for different species; hence there is a continuous supply of forest litter throughout the entire year, and its decay not being checked by frost is a continuous process.

All rocks of this eastern division show the effects of weathering to great depth, not only the igneous but the sedimentary rocks as well. In the course of the drilling operations which were carried on in this region a large amount of data was obtained concerning the depth to which decay has gone in rocks of various origin and composition, and also the products of the weathering.

PRODUCTS OF ROCK DECAY

Classes in general.—The final product of rock decay in this region is a red clay. This represents the complete oxidation of all the constituent minerals of the rock except the quartz, and the complete obliteration of the original rock structure. From this extreme the products of rock decay present all possible gradations to the perfectly fresh rock. While there are no sharp lines of demarkation between different phases of the rock weathering, the products may be conveniently though somewhat arbitrarily separated into three groups, namely, red clay, blue clay, and soft rock. The first two differ chiefly in the degree of oxidation, and the second differs from the third chiefly in the extent to which the original structure of the rock has been obliterated. The third group itself is not sharply separated from the fresh rock, but passes into it in most cases by imperceptible gradations.

Red clay.—As already stated, in the eastern division of the region under discussion all portions of the surface which rise above the margins of the alluvial floodplains are covered with red clay—the final product of rock decay.

Its appearance and doubtless also its composition vary somewhat from place to place. The bright red is varied by shades of yellow, brown, and occasionally olive green, but the prevailing tint is nevertheless very generally red. The abrupt change in color between the residual clay and the adjacent alluvial clay is very striking. The latter is never red, but is always some shade of gray or blue. The only essential difference between the two clays is in the form of their iron. In the alluvium this is in the ferrous state, forming light colored compounds. In the residual clay it is in the ferric state, and not only more highly oxidized, but the oxide is in large measure dehydrated, giving the bright red color of hematite.

The cause of this difference in the state of oxidation in clays which appear to be affected by the same conditions is doubtless the different amounts of organic matter incorporated with them.

As already described, the residual clay is very compact. It is never loosened by frost or by shrinkage cracks. The only means by which vegetable matter finds its way below the surface is by growing roots and insect burrows. The amount thus introduced is not sufficient to materially affect the chemical conditions within the zone of rock decay. The vegetable matter at the surface is so rapidly and thoroughly oxidized that the organic compounds which result from the process are not effective reducing agents when they percolate downward in contact with the red clay, but probably carry an excess of oxygen which is expended in the oxidation of the rock constituents below. In the alluvium, on the other hand, the vegetable matter while only rarely constituting a large proportion of the mass, is thoroughly disseminated through it, and controls the chemical conditions preventing the oxidation of ferrous compounds and reducing ferric compounds to the lower state of oxidation. Before the deposition of the alluvium which now fills the valleys of the region the bottoms of these valleys were covered with residual clay the same as that now covering the hills. This clay underlying the alluvium and subjected to the constant downward percolation of the reducing solutions from the latter has generally though not always lost its red color. It is often found to be mottled with blue patches where the reducing solution has gained access to the ferric oxide.

Doubtless the proportion of silica, alumina, and iron depend to some extent on the composition of the rock from which the clay was derived, but this variation is not sufficient to produce marked differences in its appearance and physical properties. The depth of this upper division is not very great, usually from 10 to 30 feet. The separation between the red clay and the underlying blue clay is usually rather sharp, although in many cases there is a band of mottled clay between the two.

Blue clay.—This division is usually somewhat thicker than the overlying red clay. While its prevailing color is blue, it varies from white to various shades of yellow and brown, depending largely upon the original composition of the rock from which it is derived. It represents the zone of complete rock decay and disintegration but incomplete oxidation. The blue color is due not to the presence of a reducing agent, but to the absence of a sufficient oxidizing agent to convert the iron into the higher oxides. It generally contains more or less abundant fragments of thoroughly weathered rock, which retain their original structure, and where it is derived from basalt it usually contains numerous boulders of fresh rock, the nucleii about which concentric weathering has taken place. The lower limit of the blue clay division is often more indefinite than its upper limit. By an increase in the number and size of the rock fragments, both fresh and weathered, it passes into the zone of soft rock. As will be readily seen, the point at which the division should be drawn is, to a large extent, arbitrary, since the distinction is at best only one of degree.

Soft rock (*saprolite*).—The red clay retains but few of the characteristics of the rock from which it was derived; hence it is fairly uniform throughout the region. In the blue clay, also, the original character of the rock is almost entirely obliterated, and it is therefore somewhat uniform. In case of the soft rock, however, in so far as it retains the original structure of the rock from which it was derived, it presents the same diversity as the hard rocks of the region. In some cases this division is wanting, and the blue clay extends entirely down to the fresh rock. This is the case with the Machuca sandstone. In other cases the blue clay is thin or absent, and there is a great thickness of soft rock. This is usually the case with the dacite.

The material classed as soft rock represents the zone of practically complete rock weathering, but of incomplete rock disintegration. The forms of the constituent minerals can usually be made out in rocks which were originally coarse grained. The original structure is generally well preserved. In the vesicular lavas the gas cavities are nearly as perfect as in the hard rock. In the volcanic conglomerates and breccias the distinction of matrix and inclosed pebbles or angular fragments is perfectly sharp, yet all the material included in this class can be crumbled in the fingers.

The extensive beds of fine basaltic and andesitic tuff which occur in the Eastern divide and elsewhere are perhaps the most easily altered rocks in the region. There is some doubt as to their ever having been thoroughly consolidated, and this may account for the depth to which they are weathered. Wherever found, even under a great mass of compact, fresh dacite, the tuffs are soft and talcose, resembling a very compact, structureless clay. The principal alteration which the material appears to have undergone is hydration. It can be easily cut with a knife, and on exposure to the air it rapidly crumbles. This material has not been placed in the class with the soft rock, although it might properly be so classed. Since the classification shown on the sections was made with a view to its practical application to engineering problems, the upper limit of hard rock does not generally correspond with the limit of rock weathering from the surface downward. The rock classed as hard usually shows more or less alteration of its constituent minerals, but not enough to affect their coherence. While this incomplete weathering does not materially affect the excavation of the rock, it becomes very important and should be carefully considered when the rock is intended for use in construction. Rock which appears to be perfectly fresh when first removed from the quarry often contains many incipient fractures, and these develop rapidly on exposure. It is probable that all of the tuff and a considerable proportion of the dacite in the Eastern Divide cut would develop this weakness on exposure, and hence would be entirely unsuited for structural purposes.

ROCK DECAY IN THE WESTERN DIVISION

Turning now to the western division, the phenomena of rock decay are found to be strikingly different, and, as already pointed out, this probably depends largely on climatic differences which prevail on opposite sides of the isthmus. The most striking difference is the almost complete absence of red color in the surface soils. This change in color coincides so exactly with the change in climatic conditions that it is difficult to escape the conclusion that the change in color is due directly to climatic causes. The prevailing color in the surface soil in the region west of the lake is a bluish gray, varying to black. It is sometimes a yellowish gray and very rarely red. One reason suggested for the absence of the complete oxidation of the surface soil and the consequent red color is the greater amount of vegetable matter which becomes incorporated with the upper layers of the soil. As pointed out in the discussion of the climate, the surface soil is alternately baked and saturated with water. The numerous cracks which form during the dry season collect leaves and twigs and when the cracks are closed by the moistening of the soil this vegetable matter is thoroughly incorporated with the clay to a very considerable depth. It may be that it is present in sufficient quantity to combine with all the oxygen which is carried down by the percolating waters and thus prevent the oxidation of the iron contained in the underlying rocks. This reducing action of the contained vegetable matter prevents the oxidation of the iron in the alluvial silts in the eastern division, and there seems no reason why it should not be equally effective in preventing oxidation in the residual clays in the western division.

Another difference at once noted is the extent to which rock decay has extended. The opportunities for determining the extent of rock weathering on the west side have not been so good as for determining its extent in the eastern division, and the rocks which are there present do not afford the same variety in composition and structure. Observations are confined practically to two kinds of rock, namely, the igneous basic rock forming the large area north of the Rio Grand valley, and the rocks of the Brito formation. The basic igneous rocks do not differ essentially from those which occur on the east side, where they are covered with a great depth of red and blue clays. On the west side, however, the residual material covering them consists of a comparatively thin layer of bluish gray clay. It is somewhat doubtful whether the thinness of this residual mantle is due to the less rapid decay of the rock or to the more rapid removal of the products of weathering. Certainly the latter factor is important, but the rate of weathering may also be very much slower under the climatic conditions which here prevail than in the eastern division. The blue clay appears to constitute practically the only product of decay, and the extensive zone of soft rock in which the minerals are entirely altered, but in which the original rock structure remains, is wanting.

The clay derived from the decay of the Brito formation is quite similar to that derived from the igneous rocks, except that it contains a notable amount of sand where it is derived from the more sandy portions of the formation. Where derived from the calcareous shales, it forms a blue or black tenacious, plastic clay. Its depth varies from nothing up to 10 or 15 feet, depending on the position in which it occurs. The greatest thickness is found in the level valleys, where the surface is practically at baselevel, and where the surface erosion is very nearly reduced to zero. On the steep hillsides, on the other hand, the same kinds of rocks are covered with a very scanty layer of residual soil or it may be entirely wanting.

So far as known, there is nothing on the west side which corresponds to the zone of soft rock generally represented in the sections from the eastern division. Wherever opportunity was afforded for observing the character of the passage from the overlying blue clay to the underlying igneous rocks, the transition was found to be abrupt, and the intermediate zone of weathered rock was absent.

Overlying the shales of the Brito formation, there is a zone of weathered rock which corresponds in some measure with the zone of soft rock generally observed in the eastern division. Within this zone the beds are thoroughly shattered by the presence of numerous joint planes, and concentric weathering has been more or less extensively developed. The mechanical alterations which the rocks have suffered, however, are much more important and striking than the chemical changes; hence in the sections this is called the zone of disintegrated rather than weathered rock.

Recent geological History

RELATIONSHIP BETWEEN TOPOGRAPHY AND GEOLOGY

The relation between the topography and the recent geological history of the region is so intimate that a description of the former necessarily involves some statements concerning the latter. The same is to a somewhat less extent true of the lithology; hence in the foregoing description of the topography and of the rock formations some of the main features of the geological history have been briefly outlined. With these prerequisite facts of topography and lithology, the geological history may now be taken up systematically and in some detail.

CONDITIONS ANTERIOR TO TERTIARY TIME

As already indicated, no rocks older than the Tertiary occur in the region of the Nicaraguan depression, so that there is only negative evidence as to the conditions which prevailed here during geological periods earlier than the Tertiary.

In the region to the northward in northern Nicaragua the occurrence of granites and crystalline schists has been described; also small areas of Paleozoic rocks. The present extent of these older formations, however, as well as their former distribution, is not known.

The region to the south in Costa Rica also contains older formations, but they are almost completely covered by the recent volcanic rocks, so that the former extent of the land in this direction also is unknown. It is quite possible that a depression of this portion of the isthmus occurred at the beginning of Tertiary time, and that a somewhat extensive land area was wholly submerged or converted into an archipelago.

EARLY TERTIARY DEPOSITION AND VOLCANIC ACTIVITY

As indicated in the description of the Brito and Machuca formations, these rocks were deposited on the sea bottom in early Tertiary time. It is assumed that during their deposition there was open communication between the Atlantic and the Pacific oceans across this portion of the isthmus, although it will be readily conceded that this conclusion is merely an hypothesis. Sedimentary formations have not as yet been traced entirely across the isthmus, and there is no other direct evidence by which this hypothesis can be proven. If, however, there had been any land separating the two oceans, its rocks ought to be recognizable at the present time as distinctly older than the Tertiary sediments or the volcanic rocks which are intimately associated with them. As already stated, no such older rocks are recognized in the region of the Nicaraguan depression, and, although the volcanic activity which was contemporaneous with the deposition of the sedimentary formations may have cut off the communication between the two oceans early in Tertiary time, it appears at least probable that at the beginning of that period, and perhaps through the Oligocene, the sea had free access across the isthmus.

The argument for the hypothesis of free communication across the isthmus in Tertiary time has been very fully made by Hill.* A single link, but a very important one, is wanting in the evidence obtained at Panama. This missing link in the evidence is supplied by the discovery of sedimentary beds on the Pacific coast of Nicaragua containing the same fossils as the beds previously found on the Caribbean side of the isthmus. Supplementing Hill's argument with this new evidence, therefore, the case seems to be definitely settled.

The conditions which prevailed during the deposition of the sedimentary rocks were somewhat shallow seas, with an abundant supply of sediment alternating between sand and mud. The sediment appears to have been chiefly derived not from a region underlain by deeply decayed rocks, but rather from unconsolidated and recently ejected volcanic material. The extremely coarse conglomerates which occur in the Brito formation along the Pacific coast and on the southwest shore of lake Nicaragua point to the proximity of active volcanoes. The coarser material supplied by these volcanoes was transported but a short distance, and shows the effect of only a moderate amount of wear. The finer material was widely disseminated, and constitutes a very considerable proportion of the sedimentary formations. These contain, however, a certain proportion of clay, doubtless derived from the residual mantle covering the older rocks which formed adjacent land areas.

The conditions at certain points were favorable for the deposition of limestone. Considerable lime is disseminated throughout the entire Brito formation, and is segregated in marly beds and in occasional lenses of pure limestone. The volcanic activity not only furnished a large portion

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* Robert T. Hill: The geological History of the Isthmus of Panama and portions of Costa Rica. Bull. Mus. Comp. Zool., vol. xxviii, 1898.

of the material of which the sedimentary rocks are composed, but it continued for some time after their deposition, and produced numerous dikes, cutting the beds, and also extensive lava flows, which in places rest upon them. This volcanic activity appears to have been much more violent and long continued near the axis of the present isthmus than on the west side.

The region between lake Nicaragua and the Pacific ocean, as already indicated, is occupied chiefly by sedimentary beds and by recent volcanic material. Only a few large areas and occasional dikes of intrusive rocks have been found associated with the Brito formation, and it is not certain that these ever reached the surface. While the coarse conglomerates along the Pacific coast demonstrate the near proximity of volcanoes, the indications are that the volcanic vents from which this material was derived were to the west of the present coastline.

The conglomerates are confined, so far as known, to the immediate margin of the ocean, and the source of the material seems clearly to have been to the westward. The similar conglomerates which occur on the southwest shore of the lake appear to have been derived from vents to the southward, and to mark the southern margin of the sea in which the Brito formation was deposited.

As stated above, the Tertiary volcanic activity was most prevalent in the region east of the lake. More than two-thirds of the area which has been examined between the lake and the Caribbean is now occupied by igneous rocks, which present considerable variety in composition and structure. It is probable that the present area of the Machuca formation does not represent its original extent, but merely a region in which the volcanic rocks have failed to wholly conceal the sediments.

The numerous beds of conglomerate and stratified ash associated with the lavas in the region eastward from Machuca point to the presence of standing water during the period of volcanic activity. This water in which the ejecta were deposited may have been a shallow sea, from whose bed the volcanoes rose, or a series of lakes formed on the imperfectly drained constructional surface. It is very difficult, however, to determine even approximately the conditions which prevailed during the deposition of this heterogeneous collection of formations. The difficulty is of course greatly enhanced by the deeply weathered condition in which the rocks are now found.

MIDDLE TERTIARY UPLIFT AND EROSION

The period of deposition in this region appears to have been terminated toward Middle Tertiary time by an uplift which was coincident with a suspension of the volcanic activity. The extent of the land after the uplift can only be determined in a very general way. It is probable that the Pacific coast was some distance farther southwest than at present, and there may have been volcanic peaks along this coast which have subsequently been entirely removed by marine erosion. The isthmus was very likely somewhat broader than now, although the elevation was such that any particular rock stratum was from 100 to 200 feet lower than at the present time. The uplift inaugurated a period of active degradation. It is probable that the surface at the beginning of this period was in general broadly undulating, with perhaps isolated volcanic peaks, but no distinct mountain chain. The uplift was accompanied by only moderate warping and tilting of the surface, for the Tertiary beds have suffered comparatively little disturbance up to the present time. Their average dips are between 10 and 15 degrees. In general the character of the deformation was such as to produce a series of gentle folds, whose axes are approximately parallel with the coastlines. This was doubtless accompanied by more or less faulting, although evidence of the latter is very meager.

The character of the present drainage makes it evident that no structures were developed in the region sufficiently well defined and pronounced to have a marked influence on the direction of the drainage. The stream courses, with the exceptions which have been already noted and which will be explained later, are such as would have resulted from normal stream development on a low, gently undulating arch.

The region now occupied by the Nicaraguan depression appears to have been originally the lowest and narrowest portion of the isthmus; hence its surface was more nearly reduced to baselevel during this degradation period than that of the broader portion to the north. A somewhat perfect peneplain was developed along its margins, and broad baseleveled valleys were extended well back to the divide, in which there were numerous low broad gaps. Although the position of the coastlines at the beginning of this period is not easily determined, their position at its conclusion may be made out with a fair degree of probability. The Atlantic coast was perhaps about where it now is, or possibly a little farther east than at the present time, for although it has subsequently been moved westward by submergence and by marine erosion, it has also been considerably extended by emergence and by deposition, so that its oscillations have about balanced each other. The Pacific coast, on the other hand, differed materially in outline from the present. As already indicated, lakes Nicaragua and Managua then had no existence, and the coastline occupied a position somewhat near that represented on the accompanying outline map, plate 30, although the line there shown is intended to represent the position of the coast at a somewhat later period.

POST-TERTIARY ELEVATION AND GORGE CUTTING

The middle and late Tertiary time, as indicated above, was occupied by a period of erosion, with the reduction of much of the region to the condition of a peneplain. In the late Tertiary or Pleistocene the region was again elevated, this time probably without deformation of its surface, although there may have been a slight arching of the isthmus on the northwest-southeast axis, and possibly also an arching on a subordinate axis west of the present lake basin. The total elevation was probably between 200 and 300 feet. The immediate effect of this uplift was to stimulate the streams to renewed activity. They began at once to trench the peneplain and the broad baseleveled valleys which they had formed in the preceding period.

The consequences of the uplift were necessarily first felt in the lower courses of the streams, and their valleys were there first lowered to the newly established baselevel. Thence the deepened channels were cut backward toward their headwaters. In the valley of the river which occupied the present position of the San Juan from Castillo eastward, various phases in the process of reduction were present. In the lower course of the stream a broad valley was developed with only a few isolated remnants of the former plain remaining. This extended upward as far as Tamborgrande. From Tamborgrande to the Boca San Carlos the valley was rather broad, but the adjacent hills retain distinct evidences of the former peneplain, and wherever the rocks were unusually hard the valley of the stream was correspondingly restricted. Between the Boca San Carlos and the Continental divide, which was then near the present position of Castillo, the stream was comparatively small and flowed in a narrow gorge. Its channel was cut down to a rather low gradient backward to the present position of the Machuca rapids. At this point was the junction of three branches, probably of nearly equal size, occupying the valleys of the Infiernito, the Machuca, and the present San Juan.

The tributaries of this river also cut down into the old valleys, and the extent to which they succeeded in lowering their channels varied with their position and size. Naturally those nearest the mouth of the stream were earliest stimulated to renewed activity by the lowering of the trunk stream into which they flowed, and hence these had the longest time in which to effect the lowering of their own channels, while those nearer the headwaters of the trunk stream were not materially affected until late in the gradation period. Thus the tributaries of the San Juan as far up as the San Francisco have lowered their channels below their old baselevel—if not entirely to their headwaters, at least well back toward them. Beyond the San Francisco the upper portions of the tributaries are found still flowing at the level of their old valleys, which they have not as yet had time to completely dissect. Excellent examples of this immature drainage are seen in the basin of the Machado, and with increasing frequency from that point westward to the Toro rapids. Thus the Machuca and Bartola are rapid streams, still actively corrading their channels almost down to their junction with the San Juan.

The stream which occupied the upper portion of the San Juan valley, as indicated above, headed on the Continental divide in the vicinity of Castillo, and receiving as tributaries the Rio Frio and other streams now emptying into the lower end of the lake, flowed northwest to the head of a bay in the vicinity of the island of Madera. This stream, like the other, was stimulated by the uplift and rapidly cut its channel backward, dissecting its old valleys well up toward the Continental divide. This old channel, now drowned by the waters of lake Nicaragua, has been traced more or less continuously from the vicinity of Madera southeast with gradually decreasing depth to the vicinity of the Balsillas islands. It may very likely have extended beyond this point, and its upper portion has been subsequently filled by the sediment carried into the southern end of the lake chiefly by the Rio Frio.

The cape which extended northwest between the waters of the Pacific ocean and the bay of Nicaragua appears to have suffered some differential uplift, its southern portion being elevated more than its northern portion. Not enough study has yet been given to the whole of this region, however, to determine with any degree of certainty the details of its recent history. Nevertheless it is known that the rivers to the south of the Rio Grande have cut their channels much deeper than those to the north, and that some of the latter appear to have been affected but little either by this uplift or by the subsequent depression. Only the valley of the Rio Grande has been carefully studied, and it is certain that the uplift there was at least 200 feet.

The active wave cutting along the Pacific coast during this and the preceding period shortened the distance from the coast to the subordinate divide on the highland forming the cape, thus rendering the length of the streams flowing in opposite directions from this divide very unequal. Those flowing to the Pacific therefore had a very steep gradient, while those flowing east to the Nicaraguan depression had a comparatively flat slope; hence the corrasion of their channels was proportionately greater by the steams flowing directly to the Pacific than by those which reached the ocean indirectly through the bay of Nicaragua. The former group, of which the stream occupying the lower portion of the present Rio Grande valley is the best studied example, cut their valleys well down toward the new baselevel nearly up to the divide, while the inner portion of the peneplain occupied by the eastward flowing streams was scarcely at all affected and the gorge cutting was confined chiefly to their lower portions, which are now occupied by the waters of the lake. It is true the main trunk stream entering the head of the bay cut its channel backward well toward its headwaters, but the tributaries from the southwest cut only shallow trenches in the outer portion of the Rivas plain and none at all in its inner portion.

The relations of coast lines and divides which prevailed at this period are represented on the outline map (plate 30). The divide between the streams flowing to the Pacific and those flowing to the bay, which, after the bay had been converted into a lake, became the Continental divide, is shown by the broken line nearest the Pacific coast. The length of the streams flowing in opposite directions from this divide is seen to be very unequal. The inequality in length is so great that before the acceleration in corrasion could be felt half way up the courses of the longer east-flowing streams it had caused a deepening of the entire channels of the shorter Pacific streams. With such advantages, the shorter streams began an active conquest of drainage area from those less favorably located on the east of the divide. The result was that at one point, where the advantages of the Pacific stream were most decided, the divide between contending streams was pushed east, and successive portions of the eastern drainage were diverted to the Pacific.

The rapidity with which different portions of the divide were shifted east depended largely on its relative hight and the length of the contending streams. The conditions were evidently most favorable nearly opposite the end of the bay, probably because the soft sedimentary rocks here extended entirely across from the ocean to the bay, while to the north and south there were considerable areas of harder igneous rocks; hence the surface had here been well reduced in the preceding period, and was favorably circumstanced for further rapid reduction.

The stream which suffered diversion earliest appears to have occupied the present position of a portion of the Tola, the upper Rio Grande, the Guiscoyol, and the lower Lajas. This stream was probably 5 or 6 times the length of its opponent on the Pacific side, so that the same fall from the divide was distributed over a correspondingly greater distance, and hence had relatively much less than a fifth of the efficiency of the shorter stream. This east-flowing stream had in the preceding period developed a rather broad valley, the upper portion of which lay between the main divide and the hills bordering the Rivas plain. The remnants of this baseleveled valley are found in the upper Tola basin, while the lower portion of that basin is very perfectly reduced to the present baselevel, only the uniform summits of a few rounded hills suggesting the former existence of a plain at a higher level.

In the upper Rio Grande basin the Rivas plain can be traced from its typical development at the present Continental divide westward through the increasing degrees of dissection to the summits of a few hills nearly down to the Tola. The inference, therefore, that the remnants of the plain observed in the upper Tola and in the upper Rio Grande valleys were originally portions of the same baseleveled plain, is fairly well established. Accelerated by the lowering of its outlet, the diverted Tola has itself made considerable progress in the conquest of drainage formerly belonging to the eastward flowing streams. It has diverted branches both of the Gonzales and Medio, the reversed streams now forming the Chacalapa and Matinga, and leaving low gaps in the present Continental divide. The Guachipilin, now flowing into the upper Rio Grande, formerly found an outlet eastward to the Medio.

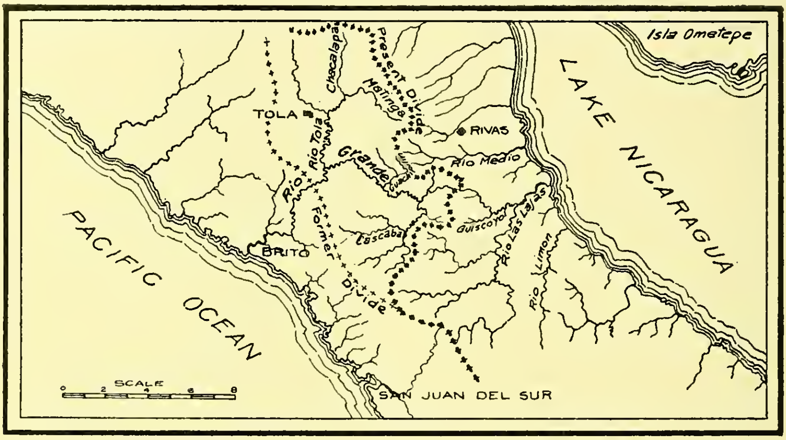

FIGURE 1.—*Basins of the Rio Grande and Rio Las Lajas.*

To illustrate recent shifting of Continental divide.

The latest diversion has evidently been the Guiscoyol, which was perhaps the largest stream in this region flowing eastward. Its source, now forming the headwaters of the Rio Grande, was in the high hills which border the lower Rio Grande valley. The Rio Grande is thus seen to have a composite course, which now makes a nearly complete circuit before reaching the sea.

The recently deserted gap between the diverted upper Rio Grande and the beheaded Guiscoyol is a broad shallow valley, its highest point being 154 feet above sealevel. It is occupied during the wet season by a swamp, from which the water appears to flow in both directions. That flowing toward the lake occupies a shallow channel, evidently once the bed of a larger stream, while that flowing west soon finds itself in a narrow, sharply cut ravine with rapid descent to the rather deep channel of the Rio Grande.

The process of diversion above outlined was inaugurated at the beginning of the high-level period now being considered, but it doubtless continued during the succeeding period after the formation of the lake. It is evident that the process is still going on, and that the Continental divide is now moving eastward at a rate which may be regarded as extremely rapid compared with most drainage changes, and, with the decided advantages possessed by the Rio Grande, it is somewhat surprising that the latter stream has not already tapped the lake.

RECENT DEPRESSION AND ALLUVIATION

The process of gorge-cutting which characterized the period of high level just described was terminated by a depression of the region, amounting to a little more than half the elevation which had inaugurated the preceding period. The effect of the depression was to drown the lower portions of the river valleys, converting them into tidal estuaries. At first the depression affected only those portions of the river valleys which were brought below sealevel, while in the upper portions the deepening of the stream channels continued as actively as before. The waste from the land, however, instead of being carried out to sea and distributed by littoral currents, began at once to shoal and fill up the heads of the estuaries. With the consequent lengthening of the streams their beds were raised, and consequently the influence of the depression was extended up their valleys at a rate corresponding to the extension of their lower courses. It is probable that the depression of the surface was comparatively slow, and the filling of the estuaries may have very nearly kept pace with their formation. As soon, however, as the depression of the land was at any point slower than the filling of the estuary the influence of the depression would proceed upstream at a rate depending upon the extension of the lower course of the river.

The depression of the land appears to have been accompanied by a moderate local warping of the surface. This warping may have affected the entire isthmus, but the means of detecting it are not at hand, except in the western portion. The Rivas plain has evidently suffered a gentle tilt to the northeast, and it is more than probable that this tilting was accomplished during the depression of the land surface. It will be recalled that the Rivas plain is a plain of degradation, formed by the action of streams flowing near baselevel. A plain formed in this way must necessarily be nearly horizontal, but the present Rivas plain has a slope to the northeast of about 8 feet to the mile. This is manifestly greater than the gradient of streams forming a baseleveled plain. It is considerably greater than the gradient of the present streams which cross it. The latter, emerging from rather deep, narrow gorges in the residual hills to the southwest, cut narrow channels in the inner portion of the Rivas plain. These channels in some cases have a depth of 60 feet or more. They gradually decrease in depth toward the outer margin of the plain, the unequal slopes of the stream bed and the peneplain surface bringing them together at the lake margin.

Accompanying the depression of the land which inaugurated this period was a renewal of the volcanic activity of the region. It is possible that the volcanism and the depression may be intimately related as cause and effect, or may be both the effects of a common cause. However this may be with regard to the depression of the region as a whole, it is more than probable that the observed deformation of the surface is due directly to the volcanic activity. This activity was manifested along two lines of vents forming the lines of volcanic craters whose topography has already been described. The southern series of vents forming the Costa Rican volcanic range broke out within a land area and possibly on a somewhat elevated plateau. These volcanoes have obliterated the preexistent topography and built up a massive mountain range. The northern series of vents forms the Nicaraguan volcanic range. Between the nearest peaks of the two ranges—Orosi to the south and Madera to the north—there is a gap of about 30 miles.

However closely the two ranges may be associated in the causes which led to the extension of their lavas and in the character of the lavas themselves, they are entirely distinct at the surface and are separated by sedimentary and igneous rocks belonging to an earlier geological period. As seen from the map (plate 30), on which the former position of the Pacific coastline is shown, the volcanic vents which formed the Nicaraguan range broke out on the sea bottom and extended nearly parallel to the west coast. The northern vents of the group were the more active, and have given rise to a somewhat continuous mountain chain and also to the extensive Jinotepe plateau.

FORMATION OF LAKE NICARAGUA

The position of these volcanic vents with reference to the coastline was such that when their ejected material had reached the surface of the sea it formed a barrier across the bay of Nicaragua. This barrier was built gradually higher by successive eruptions, and since in the area behind it precipitation was greater than evaporation, the waters rose above sea-level and doubtless escaped westward over the barrier during periods of quiescence in the volcanic activity. As the surface of the barrier was raised by successive additions of volcanic ejecta, the surface of the impounded waters was raised to a hight probably somewhat above the present elevation of lake Nicaragua. The lake thus formed occupied not only the position of the former bay, but flooded the basins of the tributary streams. Its surface finally reached the lowest point in the Continental divide, where a west-flowing stream headed against one which occupied the present position of the San Juan. When this point was reached the intermittent escape of the impounded waters across the volcanic dam to the westward was changed for a permanent outlet to the eastward.

The gap when first discovered and overtopped by the rising waters was doubtless of deeply weathered rock and residual clay. This must have been very rapidly cut down by the escaping waters until the underlying hard rock was reached, when the permanent level of the lake was established, which it has retained practically unchanged to the present time.

It is quite possible that the gaps through the Continental divide to the east and through the divide across the west strip of land between the former bay and the Pacific ocean were so near the same level that the lake had for a short time an outlet both to the Atlantic and to the Pacific.

An examination of a portion of the Rio Grande gorge possibly throws some light on this question. From the point where the Rio Grande turns abruptly to the northwest in the reversed channel of the stream which formerly flowed east, for a distance of 4 or 5 miles to the point where the gorge opens out to the alluvial plain bordering the lower river, there is an old channel which has been partially silted up by the present river. The stream only occasionally touches the rock walls of the gorge on the convex sides of its meanders. At the same time it nowhere departs wholly from the old channel—that is, it nowhere has the character of a superposed stream. It is evident that the present stream is smaller than one which excavated and formerly occupied this valley. There are three ways in which the present conditions might have been brought about:

1. The present valley might have been occupied by a stream which was once larger than at present, but which has suffered a partial diversion of its headwaters by capture through the encroachment of a neighboring stream. This possible explanation, however, is not applicable in this case, since the Rio Grande is itself a growing stream, and is constantly

adding to its drainage area and hence to its volume by encroaching on the basins of its neighbors. There is no evidence from the arrangement of the drainage in this region that the Rio Grande has ever lost any territory in this way.

2. The former volume of the Rio Grande might have been greater by reason of different climatic conditions which at some former time gave the region a greater rainfall than it now has. There is no direct evidence in favor of this hypothesis. So far as known, there is no evidence whatever that the rainfall has ever been greater in this region than it is at the present time. On the contrary, if a greater rainfall has been the cause of the old valley, this condition would have been general in its effects, and all the streams of the region would show the same evidence of greater volume in the past. So far as known, however, the Rio Grande is exceptional in this respect.

3. The third possible explanation is that the lake may have found an outlet for a short time by way of the Rio Grande valley. As pointed out above, the lake rose behind the barrier formed of volcanic ejecta until the level of the impounded waters reached the lowest gap in the Continental divide, where they spilled over and escaped by way of a river channel leading eastward to the Caribbean sea. Now the material forming the gap in the divide must have been residual clay and deeply weathered rock, material which would be rather readily removed by the corrasion of the escaping waters; also a study of the present river gorge where the Continental divide formerly existed shows that the channel has here been considerably lowered. It does not seem at all improbable, therefore, that the lake for a short time may have been 50 or more feet higher than now with refrence to the surrounding country; but if it were raised 50 feet, its waters would escape by the Lajas-Grande gap westward to the Pacific. It seems possible that when the waters of the lake were first raised by the growing barrier to the northwest, they found two gaps at approximately the same altitude, and for a time escaped in part east to the Atlantic and in part west to the Pacific. Active corrasion of the two outlets began at once. The gorge of the Rio Grande was excavated, but the gap in the main divide in the east was at first in less resistant material, and was consequently cut down the more rapidly. By the time hard rock was reached in this gap the waters had been entirely withdrawn from the western outlet. The eastward tilting of the region west of the lake may have continued well into this period, and have been in some measure instrumental in finally turning the outlet to the east.

It is possible that at first the gap in the main divide to the east was so much higher than the one to the west that all the water escaped by the latter; that the backward cutting of the east-flowing stream lowered a gap in the divide, and by reason of the less resistant material of which it was composed diverted at first a part and finally all the waters of the lake to the east. This is only a modification of the third hypothesis, and does not affect the main point, namely, that for a longer or shorter period the lake had two outlets—one by the Lajas-Grande gap and the other by the valley of the present San Juan.

This modification of the hypothesis removes one of the most serious objections to the above stated theory for the origin of the lakes. An examination of the region which it assumes to have been occupied by the Continental divide leads to the conclusion that the lowest gap in the divide was probably more than 50 feet above the present river. An elevation for the present divide above the San Juan at Castillo of 100 feet or possibly more would accord better than an elevation of 50 feet or less with the topography and drainage of the region and with the characteristics of divides in general; and it is by no means impossible that the backward cutting of the eastward flowing stream should lower the gap 50 or 75 feet in residual clay while the outlet of the lake was cutting the 4 or 5 miles of rock gorge new occupied by the Rio Grande.

The above theory for the formation of lake Nicaragua is supported by a consideration of its fauna. In a paper on the fishes of the lake, Gill and Bransford make the following statements:*

> "The element of especial interest in connection with the ichthyic fauna of the lake is the association of forms that we are in the habit of regarding as characteristically marine with those that are at least as exclusively fresh-water types. Thus with the species of Cichlids and Characinids, of which no representatives have been found in marine waters, we have a species of *Megalops*, a shark and a sawfish."
>
> "The why and wherefore of such combinations of species are not entirely apparent. They may have resulted (1) from the intrusion of salt-water types into the fresh waters, or (2) from the detention and survival of the salt-water fishes in inlets of the sea that have become isolated and gradually become fresh-water lakes. On the whole, it appears more probable that the latter is the case. By the uplift of the land an inlet of the Pacific ocean might have been shut off from communication from the ocean, and the character of the water would be soon changed by the copious showers of that tropical country. The shark, sawfish, megalops, and other species mostly found in the sea had, however, time to accommodate themselves to the altered conditions, and in this connection it must be remembered, too, that most of the types in question are known to voluntarily ascend high up streams and even into fresh water. The numerous rapids of the river discharging from the lake discourage, however, the idea that the species enumerated have voluntarily ascended that river and entered the lake."

Of special significance is the fact, not known at the time the above

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*Theodore Gill and J. F. Bransford: Synopsis of the Fishes of Lake Nicaragua. Proc. Acad. Nat. Sci., Philadelphia, vol. xxix, 1877, p. 179.

was written, but recently communicated to the writer by Dr Gill, that the sharks of lake Nicaragua are specifically identical with those found in adjacent portions of the Pacific ocean, but distinct from those found in the Caribbean sea.

SUBSEQUENT MODIFICATION OF THE LAKE

Volcanic eruptions.—The original outline of the lake formed behind the barrier of volcanic ejecta was probably quite different from that of the present lakes. The subsequent modification has been due to several agencies. The continuation of volcanic eruptions has doubtless very much contracted the northwest portion of the depression. It is probable that the original depression was occupied by a single lake which extended northwestward beyond the present limits of lake Managua. Later eruptions encroached on this portion of the lake basin, and finally a flood of volcanic ash and mud was carried entirely across the depression, forming a barrier which cut off the upper portion of the lake, raising its surface between 30 and 40 feet above the surface of the larger portion to the southeast. The strip of land separating the two lakes is a nearly perfect plain composed of partially consolidated volcanic tuff.

The Tipitapa river, which forms the outlet of lake Managua, crossing this barrier, has cut its channel backward nearly to the upper lake. It falls about 13 feet within less than half a mile of the point where it emerges from lake Managua. In a very short time, therefore, unless the backward cutting of this stream is arrested, the level of lake Managua will be lowered to the extent of 13 feet.

The original outline of lake Nicaragua has been further slightly modified by the recent volcanic eruptions in the vicinity of Madera and Ometepe, and perhaps also of Mombacho. The northeast side of the latter volcano appears to have suffered an enormous landslide, which has pushed before it a great mass of earth and rock. This now has a peculiar hummocky surface and forms a long point projecting into the lake and a large number of small islands.

Wave cutting.—The outline of the lake has further been modified by the action of the waves. The trade winds produce a nearly constant surf on its west side, and this has accomplished considerable erosion at certain points. The wave action has probably cut a shelf into the adjoining plain entirely around this portion of the lake, the extent of the shelf depending on the character of the rocks which were encountered by the waves.

In the region south of Madera bold headlands are formed by masses of hard igneous rocks which tend to protect the less resistant rocks between.

At some points the steeply inclined sedimentary rocks contain certain beds of sandstone which are much more resistant than the mass of the formation, and these form parallel ledges which extend into the waters of the lake in some cases a mile or more, the softer rocks between having been removed by the wave action to a considerable depth.

Some estimate may be made as to the extent of the wave-cut terrace along the lake shore west of Ometepe from the hight of the cliff. The Rivas plain has an average slope of about 8 feet to the mile, and it is assumed that this plain extends to the eastward under the waters of the lake. If it retains the same slope a cliff 24 feet in hight would represent a terrace at least 3 miles broad. It is probable that the wave cut terrace varies between 2 and 4 miles along this portion of the shore.

From Zapatera northward to Granada the wave action is more efficient than on any other portion of the lake by reason of the greater sweep which the prevailing winds and waves possess. Since the shore is here composed of only partially consolidated volcanic ash, the modification of its outline, due to wave action, has been very considerable. It is probable that this action has severed Zapatera from the mainland, and that the many islands surrounding it were originally portions of that volcanic cone. They probably represent the more resistant lavas from which the softer materials have been washed away.

The modification of the northeast shore of the lake by wave action has been extremely slight. This portion of the lake shore is without a beach, and only rarely is there any considerable surf; hence only a few points which project well out into the lake show any effect of wave action.

The material eroded by the waves from the western shore has been carried north by the action of the waves and deposited in the upper end of the lake. A bar has been built across the point of the lake, enclosing a broad, shallow lagoon behind it, and the outlet of lake Managua has been pushed northward by the sand drift well toward the northern margin of the valley.

Alluviation.—The third way in which the outline of the lake has been modified is by the building out of its shores by material brought down by tributary streams. The effect of this is seen almost exclusively along the south and east shores. Elsewhere the constant surf and consequent littoral currents have been sufficient to distribute the sediment as rapidly as brought down by tributary streams, so that not only have no additions been made to the lake shore, but the new material added has not been sufficient to compensate for the wave erosion. When the waters first occupied the depression behind the barrier to the northwest, the outline of the lake must have been quite irregular, since it filled a river basin some portions of which had rather strong relief. Much of its basin occupies a region which had been comparatively well baseleveled, but its waters also extended up the valleys, where extensive unreduced areas remained upon the divides. Many shallow estuaries were thus formed, and these have subsequently been entirely filled with sediment by the streams entering their heads. The most extensive filling was at the southeast end of the lake, where the largest tributaries enter it. It is evident that the broad swampy plains bordering the Rio Frio and the upper San Juan, down to and beyond the Toro rapids, were originally portions of the lake which have subsequently been silted up. The ordinary method by which lakes are obliterated is by the filling from their upper ends and by the cutting down at their outlets. In this case, however, a part of this process is exactly reversed. The lake is being filled most rapidly from its lower end. This filling is manifestly accomplished not by the water which comes from the lake, since this is practically clear, but by the tributaries which enter this lower portion.

The present river channel does not necessarily coincide with the position of the river which formerly occupied this basin. Its present position is dependent on the relative amounts of sediment brought down by the tributaries on either side. If the Castillo and Toro rapids were cut back and the channel of the river permitted to sink through the alluvium forming the greater part of its banks and bed on the oldland surface which the alluvium conceals, it would have the characteristics of a superposed stream. At numerous points where its present channel does not follow the old channel it would discover hard rocks in its downward cutting. In its present condition this may be described as a *residual river channel*—that is, a broad arm of the lake has been gradually constricted by the addition of sediments on its margin—and all that remains is the narrow river channel kept open by the current of the water flowing from the lake.

The Toro rapids, which retain the lake at its present level, are not formed by a solid ledge of rocks crossing the valley, but by boulders, sand, and clay. It is some distance below the Toro rapids that the rock is first found crossing the valley.

It appears that when this arm of the lake extended down to the Continental divide it received a rather large and swift tributary, the Rio Sabalos, near its head. The sediment carried by the Sabalos, consisting of clay, sand and boulders, was deposited on reaching the quiet water of the lake. A delta was thus formed which extended across this arm of the lake, forming a shoal. As the river channel sank in the gap across the divide the latter became lower than the surface of the Sabalos delta, and the crest of the dam, which retained the surface of lake Nicaragua, moved west from its original position on the divide to the present position of the Toro rapids. It is evident that the dam formed of this unconsolidated material is only very temporary, and that the backward cutting of the river channel, unless artificially checked, will soon lower this barrier and eventually affect the level of the lake.

It is difficult to determine exactly the position of the old divide. It undoubtedly crossed the valley of the present San Juan below the mouth of the Poco Sol. That stream has evidently inherited the lower portion of its course from a tributary to the stream flowing northwest. The Santa Cruz also probably belonged to the western drainage. The general course of the Bartola, on the other hand, indicates that it belonged to the eastern system; hence the divide was probably between the Bartola and the Santa Cruz. It may have been at the present Castillo rapids, although it is probable that the rapids would show some recession due to erosion since the lake was formed. This, however, might be comparatively little by reason of the character of the rocks and the fact that the river at this point carries comparatively little coarse sediment, and hence is relatively inefficient in corrading its channel.

Summary and Conclusion

1. The region discussed embraces the belt of country extending from the Caribbean sea to the Pacific in northern Costa Rica and southern Nicaragua adjacent to the route of the proposed Nicaragua canal.

2. Its most important physiographic feature is the broad depression which extends diagonally across the isthmus between the recent volcanic ranges on the southwest and the Chontales hills on the northeast. The topography of this depression is chiefly that of an oldland, generally reduced to the condition of a peneplain by streams flowing in opposite directions from a former divide near the axis of the isthmus.

3. The rainfall on the Caribbean side of the isthmus is very abundant and distributed uniformly throughout the year. On the Pacific side it is less abundant and confined to half the year. This climatic difference produces striking differences in vegetation, rock decay, rate of erosion, and resulting topographic forms.

4. The rocks of the region are largely volcanic products, with two sedimentary formations of Tertiary (Oligocene) age, and no rocks occur which are certainly older than the Tertiary. The igneous rocks are in part contemporaneous with the Tertiary sedimentary formations and in part recent.

5. On the east side high temperature with abundant moisture and consequent rank and rapidly decaying vegetation afford exceptionally favorable conditions for rock decay, which has extended to great depths

and yields red clay as the final product. On the west side alternate wet and dry seasons afford less favorable conditions for rock decay, and the final product is blue clay.

6. In early Tertiary (Oligocene) time there was probably free communication across this portion of the isthmus between the Atlantic and the Pacific. A great mass of sediments was deposited in a shallow sea and many volcanoes were in active eruption.

7. In middle Tertiary time the region was elevated and subjected to long continued subaerial degradation, and the narrower portion of the isthmus was reduced to a peneplain, with monadnocks at the divide near the axis. There is no evidence that open communication has existed between the two oceans across this portion of the isthmus since the middle Tertiary uplift.

8. In post-Tertiary time the region was again elevated and the previously developed peneplain deeply trenched.

9. A recent slight subsidence has drowned the lower courses of the river valleys, and the estuaries thus formed have subsequently been filled with alluvial deposits.

10. Recent volcanic eruptions have formed a barrier across the outlet of a bay which formerly indented the Pacific coast. The waters rose behind this barrier until they reached the level of a low gap in the Continental divide, when they discharged to the eastward, and the divide was shifted to the newly formed land near the Pacific coast. Lakes Managua and Nicaragua thus occupy the bed of the former bay and the basins of rivers which were tributary to it.

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EOLIAN DEPOSITS OF EASTERN MINNESOTA

BY C. W. HALL AND F. W. SARDESON

(Read before the Society December 30, 1898)

CONTENTS

Introduction

Lying on the latest glacial till in eastern Minnesota are found different varieties of eolian deposits, such as lag gravels, dune sands, and loess. The last named material lies on the higher lands, which are usually the thicker morainic accumulations, and is rarely more than from a few inches to one or two feet in thickness. On the other hand, considerable formations of dune sands and associated lag gravels lie on the leeward side of the streams.

Earlier Recognition of Eolian Deposits

These deposits are frequent not only in eastern Minnesota but in the bordering districts of adjacent states. Inasmuch as no descriptions are seen of such accumulations, the inference is that they have been regarded by the many glacialists who have worked in this region as glacial in origin and therefore described as modified drift; that is, as a water deposit rather than dune sands of eolian origin. One exceptional case is the description by Warren Upham [*] of an area of dune sand where the sand is still shifted by the wind and the nature of the deposit is for that reason unmistakable. The area referred to is in Anoka county, from 12 to 15 miles north of Minneapolis. The description is as follows:

> "Dunes of sand, gathered from the modified drift by the wind and heaped up in mounds and ridges 10 to 20 feet high, occur in the south part of sections 34, 35, and 36, Grow, Anoka county. They are blown into frequently shifting forms, like drifts of snow, and are too unstable to give a foothold to vegetation. It seems most probable that they were gathered from the coarser sand and gravel of the surrounding area soon after the deposition of those beds, before they became covered and protected from wind erosion by grass, bushes, and trees."

This is doubtless the same belt of wind-driven sands which can be seen in many places as far southeastward as Saint Paul.

One of the authors of this paper has already pointed out, although incidentally, that very much of the "modified drift" mapped in eastern Minnesota is really dune sand, but not having traversed the entire region, the full extent of the dune sand deposits was unknown.[†]

A. H. Elftman [‡] has more recently identified the same kind of deposit in northeastern Minnesota. At one locality—

> "are deposits of unstratified sand above the till and modified drift. These deposits present an uneven surface similar to that of the moraines. The material is composed entirely of fine sand. These dune-like hills are referred to wind deposits which are derived from extensive deposits of modified drift in the immediate vicinity."

DEFINITIONS OF LOESS, DUNE SAND, AND LAG GRAVEL

Before describing some typical occurrences of this kind it may be recalled that the recognition of dune sand, so far as cited, is based on structural peculiarities of the sand and its relation to the till and modified drift.

Loess, so far as here observed, is an eolian deposit. It is accumulated by long continued winds blowing prevailingly in one direction. This accounts for its leeward position wherever found. The material composing it undoubtedly springs from glacial deposits, since these have effectually covered all older rock formations within a wide region.

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[*] Geology and Nat. Hist. Survey of Minnesota, vol. ii, 1888, p. 418.

[†] F. W. Sardeson: On glacial deposits in the driftless area. American Geologist, vol. xx, pp, 392–403.

[‡] The geology of the Keweenawan area in northeastern Minnesota, pt. 1. American Geologist. vol. xxi, pp. 90–109.

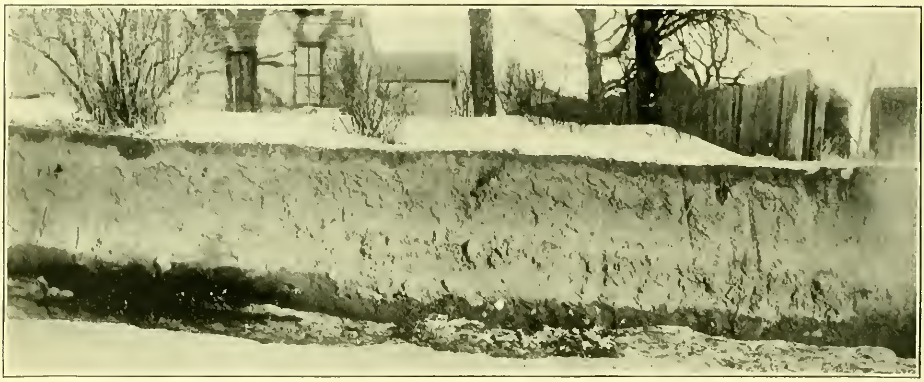

Figure 1.—Section on Pleasant Street, near Washington Avenue

Showing dune sand of considerable thickness overlying stratified sand and pebbly till

Figure 2.—Section at Foot of Pleasant Street

Showing ancient river gravel covered by stratified sand and peat and underlain by Trenton limestone. Taken at point "*f*" in generalized section, figure 2, page 360

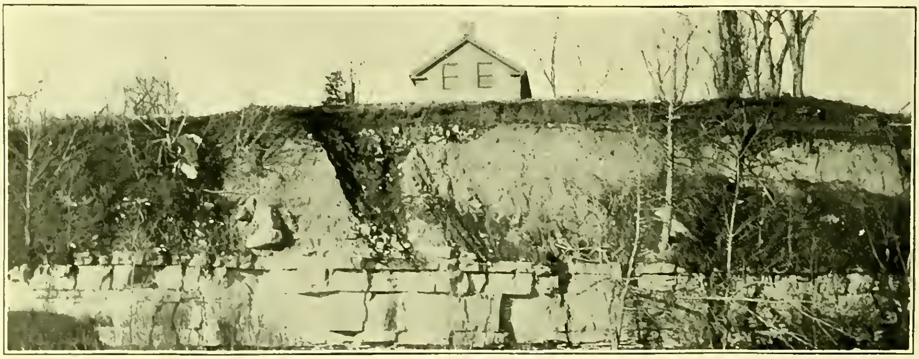

Figure 3.—Section to Eastward of that of Figure 1

Lag gravel covered by dune sand. Eolian deposits overlie till which extends from eroded surface downward to top of limestone. Taken at point "*g*" of figure 2, page 360

EOLIAN DEPOSITS IN MINNEAPOLIS, MINNESOTA

Dune sand is the wind-blown sand of much coarser texture than the loess. Its coarser particles are pushed along the ground, while the finer form clouds of dust in the air which settle rapidly or slowly, near to or remote from the source of supply, according to the force of the wind and the size of the particles suspended.

Lag gravel is the coarser material of worn or subangular habit which moves heavily along the ground, pushed by violent winds through short distances. This material sustains the same relation to the dune sands as the latter do to loess. Hence we have in these three characteristic accumulations three different phases of eolian deposits, comparable in their several relations to each other to three characteristic accumulations under water, namely, gravel sand, and clay.

The identification of the eolian deposits therefore depends on skill in distinguishing between wind deposits and water deposits.

Loess

GENERAL CHARACTERISTICS OF MINNESOTA LOESS

The loess as a deposit in this region is never more than a thin veneer seen occasionally on the higher hills. It is therefore scarcely a typical loess, since being near the surface the humic acids have from the time it was laid down had ready access to it. The deposit in most places has been entirely reduced or exists in the soil only. When two or three feet thick, as it sometimes is, it is distinguishable from the till only on close inspection, the slight differences in color and composition needing the additional presence of pebbles in the till and a stratified arrangement when "modified" to make discrimination easy. Whenever it occurs in thinner layers there is but little material that can be distinguished from the associated soil. The wind-borne dust was not deposited rapidly enough to produce deep and widespread beds of loess.

LOESS IN SAINT PAUL

As a typical locality a bed of loess in Saint Paul is shown on plate 33, figure 1, and briefly described. It is one of many such thin layers to be seen throughout the eastern portion of the state. On Como avenue, near the Como-Harriet interurban electric railroad, is an exposure showing the following sequence downward :

1. Dark colored soil from 4 to 8 inches in thickness, supporting the usual amount of vegetation.
2. Loess of a light pinkish gray color, wholly without stratification, fine and non-indurated in texture. Its thickness varies from 2 to 3 feet. It is distinguished from the till by the entire absence of pebbles or layers of sand.
3. Clayey till. For 5 feet of its thickness this layer is a fair quality of clay, but it gives place downward to a bed of gravelly till.

The horizontal distribution of this bed of loess can not so easily be measured. With many interruptions, it probably extends over a considerable portion of the Saint Paul lake area outlined by Upham.*

Another locality in Saint Paul is near the new state capitol now under construction. On the top of a pure gravel bed or accumulation of modified drift 30 or more feet thick lies a bed of loess 3 feet and more in thickness. It is characterized by its clayey consistency, and this is easily distinguished from the dune sand deposits, which are much more frequent.

ORIGIN OF THE LOESS

The problem of the origin of the material of the loess of eastern Minnesota is not further attacked. Its blanket-like distribution, its evanescent relations to the soil above and the undoubted water or ice deposit below strongly suggest that the material springs from the finely subdivided glacial debris which was comminuted and scattered during the periods of the successive ice invasions.

Touching the further question of evidence that the loess is of eolian rather than aqueous origin, the following points only can be summarily stated: 1. The loess does not occur in any of the thousands of Minnesota lakes, existing and extinct, whose deposits have been dissected. 2. It does occur on the higher levels of the glacial drift. 3. When in relation with the dune sands it is found higher than they, whereas as a water deposit it should be lower—that is, farther from the shoreline of deposition. 4. It is frequently liable to carry loam within it, thus pointing to zones of vegetation.‡

Dune Sand

EXPLANATION OF ITS CONSPICUOUSNESS

The dune sand is a much more conspicuous accumulation than is the loess. The nature of the material explains this fact. It is due not only to its coarseness and other physically resistant qualities as a rock, but also to its greater capacity to resist the corroding and dissolving properties constituent in and derived from soils. From the scores of localities where it can easily be seen the following are cited:

SNAKE RIVER VALLEY

Pine City.—An interesting exposure of dune sand occurs at Pine City, Pine county, Minnesota ‡ (see plate 34). At this point Cross lake forms

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* Warren Upham: Modified drift in Saint Paul, Minnesota. Bull. Geol. Soc. Am., vol. 8, pp. 183–196.

† Compare F. W. Sardeson: What is the loess? Amer. Jour. Sci., 1899, vol. vii, pp. 58–60.

‡ This is also a spot of historic interest. In one of the severe battles fought in the early years of the century between the Chippewa and Sioux Indians the former took advantage of the elevated situation and soft fine sand of this dune sand plain to build entrenchments, in which they defended themselves successfully against their enemies. The profile of the entrenchments is indicated in the picture.

DUNE SAND AND MODIFIED DRIFT AT PINE CITY, MINNESOTA

Upper portion is fine, brownish gray, non-stratified dune sand. Below dune sand lies modified drift, somewhat argillaceous and distinctly stratified. Lower portion of view is lake debris visible at low water

an enlargement of Snake river, due to the obstruction presented by the remarkable series of lava flows of Keweenawan diabases, diabase amygdaloids, tuffs, and associated conglomerate beds which begins at the foot of Cross lake and extends down the river for nearly 2 miles. Along the north side of the lake the modified till is capped by an unusually deep and wide exposure of dune sand.

The exposure is a typical one. The loess-sand at the top is from 2 to 4 feet thick along a vertical front facing the lake for hundreds of feet. It is of fine texture, brownish gray in color, and non-stratified and furnishes a subsoil through which roots of trees, shrubs, and grasses readily make their way. The color and texture are the same as at other localities. Below this cap of wind-deposited material is a fine evenly textured stratified sand. This modified drift is somewhat argillaceous and holds water more tenaciously than the dune sand above it, thus producing zones of springs. It extends downward at least to the water, thus making a minimum thickness from 8 to 10 feet. The color and composition of the sand are nearly identical with those of the overlying eolian drift, but the distinction of stratification in the former is sharp and clear.

Other localities in Snake River valley.—At the mouth of Snake river, in section 36, township 39, range 20 west, and section 31, township 39, range 19 west, lie extensive exposures of an eolian sand plain. The glacial drift consists of a fine pink clayey sand somewhat stratified ; the water deposit is a bed of modified boulder till lying upon the former. The most conspicuous exposure of the wind deposits of the locality lie above these near the junction of the Snake and Saint Croix rivers. A high ridge of modified drift lies somewhat parallel to the Saint Croix river and one-fourth mile distant; this has been cut squarely through by the Snake. To the east of this drift extends an eolian sand plain, nearly level and occupying the entire triangle between the ridge and the two rivers. The dune sand composing this eolian deposit is from 15 inches to 3 feet in thickness, and is covered with a heavy vegetation.

KETTLE RIVER VALLEY

Along Kettle river are several interesting exposures of eolian sands. From them a plain in section 32, township 40, range 19 west, is selected as particularly interesting. Its extent could not be determined, owing to its lying in a forest region, but it is estimated to be several miles long and stretches northward and southward on the east side of the river. In the south part of the section the river in its southward course strikes a mass of hardened Keweenawan diabasic tuff and is deflected squarely to the east. Soon a stretch of the river is reached where for nearly half a mile the north bank has been freshly cut by floods, and there stands disclosed one of the most magnificent exposures of till and modified drift to be seen in the State. Its entire thickness is shown from the diabase floor to the eolian sand-cap.

This overlying eolian sand varies from 1 foot to 3 feet in thickness, and is easily distinguished from the glacial drift on which it rests by its lack of stratification, pink gray color, uniformity, and fineness of texture. Its position indicates clearly that it was not formed by the river while flowing in its present bed. The probability is that it was accumulated contemporaneously with or immediately succeeding the glacial deposits of the region.

Along this same stream are other exposures. Within this same township and section can be seen another view of the same sand plain just briefly described. It presents no new nor varying features.

OTHER LOCALITIES IN THIS REGION

At White Bear, 8 miles north of Saint Paul, there is seen beside the tracks of the Saint Paul and Duluth railroad a prominent deposit of wind-driven sand. It is from 2 to 4 feet thick at the point exposed. Other places within the village and vicinity show undoubted eolian deposits, without indicating their total thickness. From observations made it would appear that the village of White Bear is built on an extensive deposit of dune sand and loess accumulated before the present soil was formed.

Northward from White Bear, along the line of the same railroad, and particularly between the stations Harris and Rush City, the fields and railway cuts bear the peculiar dune features. Along the line of the Eastern Minnesota railroad, recently graded, from Minneapolis to Long lake, 3 miles north of Cambridge, dune sands and loess sands are strongly in evidence. The latter sometimes show a banding of finer loessial material, which retains moisture longer, thus showing plainly on cross-sections, particularly after rains. This material indicates a tendency to merge into "loess-loam," such as is occasionally found around Minneapolis and Saint Paul. These dune sands attain a thickness in some of the railway cuts of from 8 to 15 feet. Indeed, the underlying till, almost without exception, is not reached in the whole long series of railway cuts which this line now shows.

WISCONSIN EXPOSURES

Within the Saint Croix River valley, on the Wisconsin side, the glacial drift is generally distributed. Overlying it almost everywhere is a wind-drifted covering of fine unstratified sand. Nearly all the material, both the ice, the water, and the wind deposits, comes primarily from the degraded pink Cambrian sandstone which underlies the surface and later deposits of the entire upper Saint Croix River valley, and for a considerable portion of the valley overlies the Keeweenawan eruptives. A good exposure of eolian sand was seen last autumn at Grantsburg, Wisconsin, where in recent road improvements a cut several feet deep had been made into the modified till; overlying this material was a bed of dune sand 3 feet and more in thickness.

EAST MINNEAPOLIS

At the corner of Tenth avenue southeast and Como avenue, Minneapolis, is an exposure of special interest. The section of Glacial and post-Glacial succession is as follows, in descending order:

1. A bed of Minnesota slough peat with a thin layer of soil and vegetation covering it. The peat is fairly pure save in the local segregations of gray material which consist of a mixture of peat and corroded and crumbling molluscan shells chiefly of gasteropods. These segregations are due either to the occurrence of colonies of molluscan forms which were located at these spots, or to the driving together of large numbers of abandoned shells by wind action, as is often seen in the lakes of Minnesota at the present time. The peat layer varies from a few inches to 2½ feet in thickness.
2. Lying directly beneath the peat and quite sharply separated from it is a layer of dune sand. The color of this sand is a light gray with a somewhat pinkish tint; its texture is fine and even; structurally it has no trace of stratification whatever, so far as can be seen. It carries no fossils, while the peat above it has many. The dune sand layer varies in thickness from 6 feet down to complete disappearance; it is about 2 feet thick where the peat now lies heaviest on it. It contains, wherever the exposures permit examination, many decayed roots or canals which once were filled with roots. Decomposition has gone so far that it is impossible to identify the plant forms.
3. Next in downward succession is a layer of soil; it is a sandy loam and varies in thickness from 1 to 2 feet. The dark color, which characterizes it and plainly marks it off from the overlying dune sand and the underlying modified till, plainly is due to the intermingled vegetable debris. This soil, like the eolian sand above it, is thickly penetrated by many small roots having a prevailingly vertical direction. Their presence indicates a subsequent vegetation. The contact of this soil layer on the modified drift beneath it is decidedly irregular. Tubes of soil extend downward from 1 to 2 feet as if the soil had become packed into rodent burrows; again, charges of sand seem thrust upward, almost or quite reaching the dune sand layer.
4. Below layer 3 lies the characteristic modified drift which, so far as known, extends downward to the glaciated surface of the Trenton limestone, probably not less than 30 feet. Locally it is beautifully cross-bedded and occasionally a large boulder is seen.

The locality just described is apparently a mound. Standing on its top, other mounds can be seen in either direction, southeast or northwest. In the latter direction the dune-like elevations extend for miles.

The Grow dunes mentioned by Upham* are in all probability simply occurrences in the same ridge or series of ridges skirting the Mississippi valley along its northeast side—that is, where the prevailing west and southwest winds would deposit their load of sand and dust picked up from the river and its numerous sand flats. The mounds of sand which can be followed still farther northwestward than the district around Princeton are believed to belong to the same belt and owe their origin to the same causes. They extend as far north as Brainerd, 60 miles farther from Minneapolis than is Princeton.

SAINT ANTHONY HILL AND THE UNIVERSITY CAMPUS

The old Saint Anthony hill, once a landmark standing over Saint Anthony falls, now nearly leveled in the grading of the city, consists of a sand dune 10 to 12 feet high built upon a mound of glacial debris. The height of its summit above the Mississippi river at the crest of the falls must have been at least 50 feet. During the past year excavations have been made which have exhibited in striking profiles sections of this great thickness of dune sand.

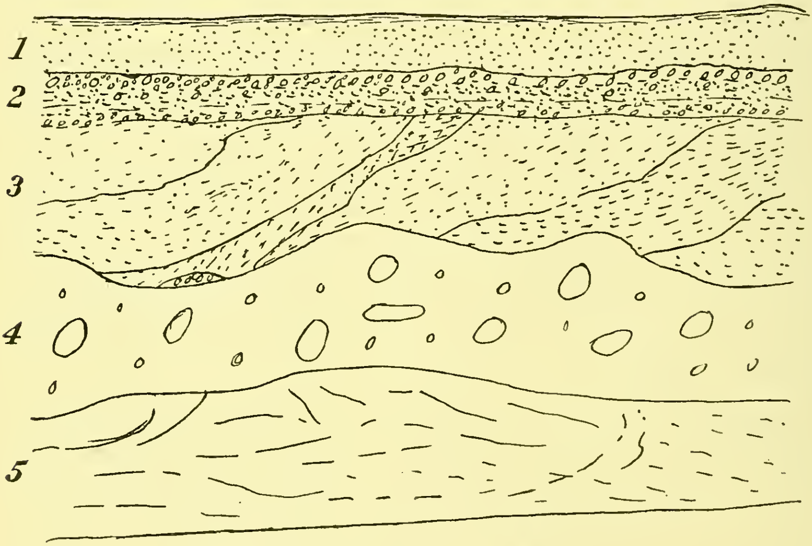

FIGURE 1.—*Section of Glacial and post-Glacial Deposits.*

The locality is the railroad cut south of the University campus. Number 1 is regarded as dune sand bearing soil 5 feet in thickness; 2, gravel with lag gravel in the top; 3, 4, and 5, various phases of the Glacial drift. After N. H. Winchell.

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* Warren Upham: Modified drift in Saint Paul, Minnesota. Bull. Geol. Soc. Am., vol. 8, pp. 183-196.

On the campus of the University of Minnesota 20 years ago dunes of sand drifted about to such an extent that the driveways were continually changed during the summer season by the efforts of the teamsters to drive around the accumulating sand piles. On the opposite side of the street, along the south side of the campus, a railway cut was made some years ago. Professor N. H. Winchell has published quite a detailed description of the glacial drift profiled at that time.* From this description it would appear that the dune sand reached a thickness in one spot of 5 feet. This was 650 feet east of the brink of the river gorge (see figure 1). At 550 feet from the river the "loam, sandy, not distinctly stratified, alluvial" deposit was 4 feet, and at 350 feet from the river the "alluvial, sandy loam" was only 3 feet in thickness. Figure 2, plate 33, shows this same deposit in a neighboring exposure.

The process of dune-making is apparently the same now as it was hundreds of years ago, before the Minneapolis peat bed began to form.

RELATION OF DUNE SANDS TO TERRACE GRAVELS

It has been possible also to establish another line of proof of the nature of the dune sands based on a discovered relation between them and Mississippi river sands and gravels. As has just been described, the campus of the University of Minnesota is underlaid by several feet of fine, loose, unstratified sand. This sand rests upon gravel, and this in turn upon the till.† The uppermost layer in this section is dune sand. Its relation to the post-Glacial river gravels of the Mississippi can be seen near by in a way to furnish proof of the eolian nature of the sand deposit. At the foot of Pleasant street, southeast Minneapolis, only a few blocks away from the campus, is the spot referred to. This is opposite the old landing which marks the exact head of navigation of the river. Here still remains a part of the river channel, which was formed before Saint Anthony falls existed at this point. The position of the falls is now one and one-half miles above this point. The old channel and the gravel deposit now lying within it must be several thousand years old; at all events, older than the time when the falls had reached this point in their retreat. The old channel mentioned is cut a little into the blue limestone layer, which in south Minneapolis is about 12 feet thick. It is probable that this channel was abandoned by the river while the falls were yet some distance farther down the stream. The now existing Saint Anthony falls are approached through a channel cut into this same bed of blue limestone, and the crest of the falls is over the underlying socalled

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*Geological and Natural History Survey of Minnesota, Final Report, vol. ii, 1888, chap. xi. The geology of Hennepin county, pp. 297–299, figs. 17, 18, 19, and their descriptions.

†Compare also N. H. Winchell's figures, loc. cit.

buff limestone bed. Therefore in the retreat of the falls the lowermost or buff limestone blocks alone are piled in the bed of the river. The same character of river debris continues from the present falls to and beyond the point where the ancient river gravels under discussion now lie, and it is believed for that reason that the condition of the falls has long been the same, and, further, that the falls were far below this point at the time the ancient channel was abandoned, leaving the gravels which are now found in place.

The old channel or part of a channel borders the northeastern crest of the present river gorge. Beyond the crest is the terrace which was once the river bank; still beyond that is seen a higher and probably "glacial" river terrace. The channel and lower terrace are now cut across obliquely by a stone quarry, and the succession of deposits above the limestone is well exposed (see plate 33, figure 3). There is seen a gravel derived from the drift and bearing numerous fossil shells identical with those now found in Minnesota lakes and rivers, namely, *Paludina*, *Limnæus*, *Sphærium*, and *Unio*. The gravel is about two feet deep, yet varying, and rests directly on the limestone bed of the then channel. Traced up the terrace, till is found gradually to intervene between the gravel and the limestone. The gravel rises on the surface of the 15-foot bank or terrace of till and merges into a lag gravel of less thickness lying on an eroded till surface. The shells which have been named occur half way up the sloping bank—that is, about 8 feet above the floor of the channel.

On the gravel in the old channel rests one foot or less of partly stratified sand with fragments of shells. This sand graduates up the terrace into a dune sand 3 or more feet thick, as now seen, which extends farther over the adjoining plain and northwestwardly many miles. Over the sand in the channel at the foot of the terrace there lies a bed of peat of impure composition and varying texture, from 3 to 4 feet thick. The peat thins out as it rises the slope and merges into the soil of the plain.

In this section is seen sufficient evidence to prove that the Mississippi river existed as such when the sands on the plain were being deposited. It had already formed a narrowed channel and flood-plain like those which now obtain above Saint Anthony falls. The shells abundantly scattered through the river gravel and up the side of the terrace show the extent and height of the river's domain at the time the shells were inhabited; at least, they prove the molluscan fauna to have been here before the falls of Saint Anthony had reached Minneapolis, and give special import to the *total absence* of like shells in the gravels and sands of the plain. Had these deposits above the bank or terrace been found within the river's flood-plain they should bear shells up to and especially along the limit of the highest flood line. Further, the same structural differences are seen between the river sand and the dune sand on the bank or terrace as are commonly seen between modified drift and dune sands throughout this region.

TIME OF FORMATION OF DUNE SANDS

The time when these dune sands accumulated can not be exactly determined, although whenever the revision of the Saint Anthony Falls recession shall be undertaken their comparative age may be quite exactly defined. No further estimate will now be attempted than this: The falls, which have receded about 8 miles since Glacial time in this region, had not begun the last fourth of their now accomplished work at a time when the dune sands were comparatively as now. They have doubtless been drifting ever since the time of the glacial retreat from this area.

Lag Gravels

As will be seen from the foregoing statement, lag gravels * frequently occur on the till and modified drift. The pebbles composing them are derived from the drift and are distinguishable from their association on the drift, and more often from their smoothly polished surfaces—especially upper surfaces, which are quite evidently planed by wind-driven sand.

Summary

Loess is found as a thin veneer widely distributed throughout eastern Minnesota. It lies on many of the drift hills and plains, but its accumulation was seemingly too slow for the formation of "bluff loess;" hence it appears as "loess-loam."

The contemporaneous dune sands are far more abundant than the loess; they are widely distributed, typical exposures being described from separated localities, as Minneapolis, Pine City, and the banks of Kettle river. Deposits equally well marked and extensive are seen in adjoining Wisconsin.

Lag gravels are noted in a few localities, as Minneapolis. These deposits are recognized by their position at the top of the unmodified and modified till and their content of pebbles with polished upward lying surfaces.

These eolian deposits are always distinguishable from the drift material

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* J. A. Udden: The mechanical composition of wind deposits. Augustana Library Publications, no. 1, 1898, p. 7.

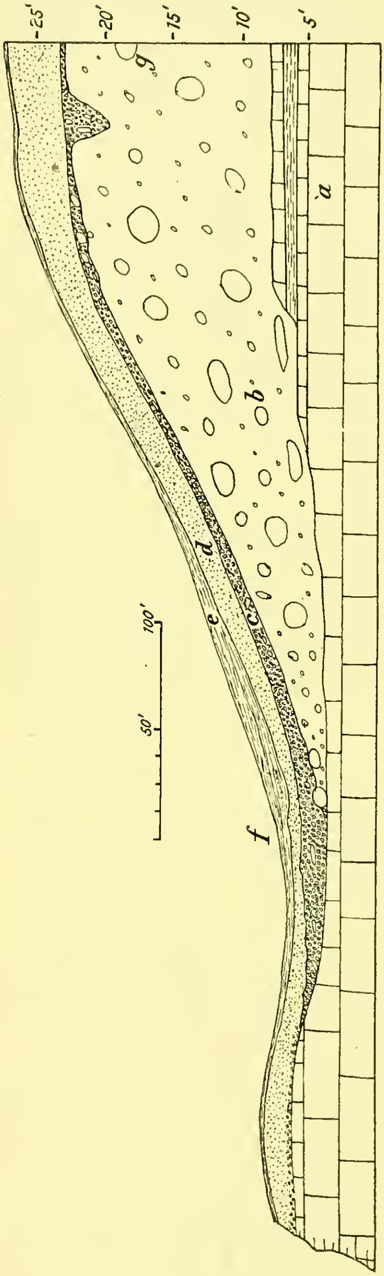
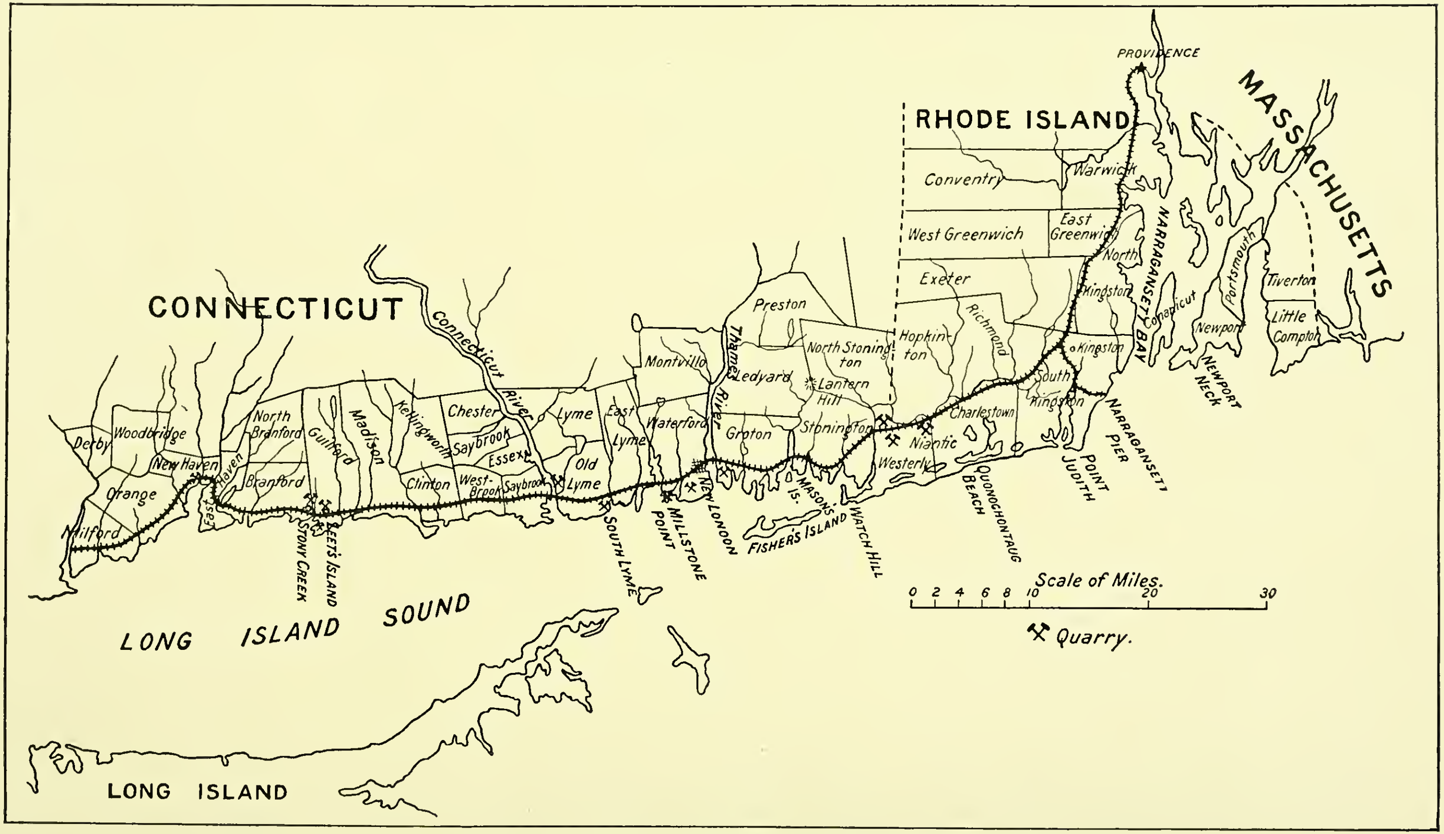


FIGURE 2.—*Section from Edge of Mississippi River Gorge across ancient Channel Bed.*

This drawing locates figures 2 and 3 of plate 33 by the letters *f* and *g* respectively. *a*, Trenton limestone; *b*, Till; *c*, River gravel on the left, graduating into land gravels toward the right; *d*, Sand stratified on the left of the spot indicated at the letter *d*, but becoming dune sand on the top of the terrace; *e*, Peat and soil.

by their superjacent position which also determines their relative age. Their relation to fluviatile post-Glacial deposits is that of a contemporary. At Minneapolis the fossiliferous gravel, stratified sand, and marsh peat of an ancient Mississippi River channel were formed contemporaneously with the lag gravels and dune sands lying on the terrace which was the bank of the river prior to the time when Saint Anthony falls were situated one and one-half miles below their present position. The relation of the eolian deposits to the fluviatile and these in turn to the glacial drift is evidence that the river's domain at that time was within a channel, and, further, that the earlier formed terraces were neither a lake accumulation nor a glacial river product. Incidentally the accompanying section (figure 2) shows that the Mississippi river has done an amount of work in addition to the cutting of the gorge in which it now flows, on which cutting estimates of the length of post-Glacial time as determined by the Mississippi river are often based.



MAP OF SOUTHERN CONNECTICUT AND RHODE ISLAND

Showing distribution of granite quarries

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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GRANITES OF SOUTHERN RHODE ISLAND AND CONNECTICUT,* WITH OBSERVATIONS ON ATLANTIC COAST GRANITES IN GENERAL

BY J. F. KEMP

(Read before the Society December 30, 1898)

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*The writer became interested in the granites here described about ten years ago, while spending summer vacations in Rhode Island. The observations have accumulated year by year since then, and in their collection important assistance has been received from Gilbert van Ingen, W. D. Matthew, and B. F. Hill, to whom acknowledgments are here made.

Outline of the Geology of the Area discussed

The area of crystalline rocks which stretches along the north shore of Long Island sound from Narragansett bay to the New Haven Triassic embayment has received almost no geological study since the state survey of C. T. Jackson,* in 1840, in Rhode Island, and that of J. G. Percival,† in 1842, in Connecticut. To the eastward, the region of Carboniferous and Cambrian strata around Narragansett bay has been quite fully described; to the northward, the central portion of Massachusetts has been shown to consist largely of altered Cambrian sediments, now in the form of gneisses, and to the northwest and west, the Triassic and metamorphosed Cambro-Silurian strata have received detailed attention, but the triangular area forming central Connecticut, with its base on Long Island sound, remains almost entirely for the future. The rocks are prevailingly granitoid gneisses, presumably of Archean age. They are penetrated by intrusions of granite, of unknown age, which, with their attendant pegmatites in the shore district, are the subject of the present contribution.

The western shore of Narragansett bay is formed of Paleozoic schists and granite where the rocks are not concealed by glacial deposits, but a mile or two to the west, in the ridge of Tower and McSparren hills, the gneisses appear and continue without a break, except for the intruded granites, until the red shales and sandstones of the Triassic are met, a few miles east of New Haven. The east and west distance is about 100 miles. The topography is of a pronounced glaciated type. Low, rounded ridges and knobs of rock project through the mantle of drift, and afford the exposures on which one must base the study of the hard geology. Along the shore the drift often conceals all outcrops of rock for miles at a time, but especially in Rhode Island it gives some compensation for this by presenting some of the finest examples of morainal hillocks and glacial dumping grounds in the east. Between the hillocks are the usual small ponds. In Connecticut the morainal hillocks are much less pronounced and abundant, but, on the contrary, narrow rocky points run out into

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*C. T. Jackson: Report on the Geol. and Agric. Survey of Rhode Island. Providence, 1840.

†J. G. Percival: Report on the geology of the state of Connecticut. New Haven, 1842.

the Sound, with stretches of salt marsh and meadow between them.* The coast is plainly one that has been drowned by recent submergence. Several of the rocky points contain intrusions of granite, which furnish material for quite an important quarry industry.

The gneisses are with few exceptions granitic in composition, and mineralogically are very similar to the massive granites. They contain, however, noticeably more of the dark silicates than do the latter. The chief component minerals are quartz, orthoclase, microcline, rather acid plagioclase, and biotite. The biotite is of a greenish brown color, and has the characteristic strong pleochroism. Magnetite, apatite, and zircon, the usual accessories in such rocks, are not lacking. In one or two instances garnet has been observed. Mechanical deformations are very widespread, and are often of an extremely pronounced character. The quartz and feldspars are crushed and granulated, and the biotite is rubbed out into long strips and bent and bowed in a striking manner. The foliation is always pronounced, and it may at times almost reach the extreme of a schist.

On Kingston hill, Rhode Island, in the ridge on which is located the village of Kingston, the gneiss contains many augen of feldspar, and is of a marked augen variety. It is so characteristic that it may be called the Kingston type of gneiss in distinction from that of the remainder of the area. There is little doubt that it is a sheared porphyritic granite, but there may have been considerable recrystallization of the material during metamorphism. The Kingston type of gneiss is well exposed in the quarries of the Rhode Island College of Agriculture and Mechanic Arts.

In a gneiss that forms the wall-rock of the granite in the east quarry of the Smith Company, at Westerly, considerable hornblende was observed along with biotite, and the same mineral has been noted in exposures east of Chapman pond, Westerly, Rhode Island, and at Clinton, Madison, and Rocky point just west of Niantic, all in Connecticut. Abundant quartz and feldspar were also present, so that the rock is essentially granitic in its mineralogy, and quite different from the basic hornblendic gneisses to be presently described.

An average hand-specimen of the biotite-granite-gneiss was selected and its specific gravity was determined to be 2.704, a value about 0.05 to 0.07 above the ranges of the massive granites and due to the relatively greater abundance of biotite.

At somewhat rare intervals throughout the gneissic area bands of basic hornblende-gneiss or amphibolite are found interfoliated with the

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*Compare in this connection J. D. Dana: On the geology of the New Haven region, with special reference to the origin of some of its topographical features. Trans. Connecticut Acad. of Arts and Sciences, vol. ii, 1870, p. 45.

granitic gneisses and strongly contrasted with them. They occur at several points in the township of Westerly, Rhode Island, in its northern portion. One of them is illustrated in plate 38, figure 2. A good exposure is shown in the village of Stonington, Connecticut, where the eastern branch track to the steamboat landing leaves the main line. Another one occurs in the railroad cuts between Stony creek, Connecticut, and Leets island. Additional occurrences are noted by Percival in still other places.

In thin-section it is seen that hornblende of a greenish brown color makes up half the rock or more. A little biotite may accompany it. The prevailing feldspar is plagioclase, but orthoclase and even a little quartz are not entirely lacking. Titanite is a frequent and characteristic accessory. Magnetite and apatite do not fail. The exposure near Stony creek contains garnets that are full of inclusions. These rocks have a pronounced foliation, and whether they are considered basic segregations in the original, more acidic magma that has yielded the granitic rocks from which the prevailing gneisses have been derived, or whether they are regarded as later basic intrusions or some still different original, certain it is that they have passed through the same dynamic metamorphism as the gneisses. Their chief interest lies in the fact that they are met as inclusions in the massive granites and are one of the most significant phenomena connected with them.

The strike of the gneisses varies more or less, but it is prevailingly northeast or northwest.

THE GRANITES

DISTRIBUTION

The several places described in the following pages are shown on the map, plate 35. Intrusive granites have long been known and recorded on Newport neck and Conanicut island, Rhode Island. The latter occurrence has been most fully described by Pirsson,* who regards the granite as intrusive in Carboniferous slates, in which it has developed some very interesting contact zones. The granite is a coarse porphyritic variety and contains quartz, orthoclase, oligoclase, titanite, magnetite, zircon, apatite and secondary chlorite, epidote, sericite, and calcite. It is so badly altered that the original ferro-magnesian mineral could not be identified with certainty, but it was presumably biotite, with the possibility that some hornblende was also present. A chemical analysis yielded the following results :

SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	H_2O	Sp. gr.	Total.
71.23	0.21	13.64	1.70	1.00	0.05	0.75	2.31	3.55	3.79	1.72	2.69	99.95

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* L. V. Pirsson: On the geology and petrography of Conanicut island, Rhode Island. Amer. Jour. Sci., November, 1893, p. 363.

Several narrow dikes of minette accompany the granite, which are, so far as known to the writer, the only basic dikes yet discovered along the Rhode Island and Connecticut coast east of the Triassic traps and exclusive of the peridotite of Iron Mine hill, Cumberland.

Almost exactly the same area and phenomena as those described by Pirsson formed the subject-matter of a paper by Collie,* which, however, makes no reference to Pirsson's observations or those of any previous writer. Collie differs from Pirsson in concluding that the granite was intruded before the Carboniferous. He shows that the minettes are later than the granite, as one dike of them cuts the granite. Crosby † has recently examined the same area, and also the related one at Newport neck. He reaches the same conclusion as Collie as to the age of the granite, and refers it in particular to the Cambrian.

Granites similar to the above occur on the west shore of Narragansett bay, between the Bonnet and the Pier. They are extensively accompanied by pegmatite dikes.

Between Narragansett bay and Niantic, where the first granite quarries are met, there are occasional outcrops of massive granites in the gneisses, but they have not been opened up by any quarry industry and present no features differing essentially from the more significant exposures further west. About a mile south of the railway station at Niantic, Rhode Island, on a hill in the midst of woods, quarries have been opened in a finely crystalline gray granite, practically like that at Westerly. Contacts with the gneissic walls are well shown, as are pegmatites and other phenomena characteristic of the granite intrusions.

About 5 miles south of Niantic, over a drift-buried area, is the small summer resort known as Quonochontaug beach. It is located immediately on the seabeach, in the neighborhood of some ledges of coarse biotite-granite. In a scattered group of boulders on the shore is the large one of orbicular or spheroidal granite, which was described and figured by the writer some years ago.‡

The granites are most extensively opened up for study in the vicinity of Westerly, in the extreme southwestern corner of the state. Two hills respectively south and north of the railway have furnished large amounts of stone, especially for monumental work. There are two contrasted varieties of granite. One is a finely crystalline gray variety and is the only one present in the southern hill, where it is quarried by the Smith

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*G. L. Collie: The geology of Conanicut island, Rhode Island. Trans. Wis. Acad. of Sci., Arts and Letters, vol. x, March, 1895, p. 199.

† W. O. Crosby: Contribution to the Geology of Newport neck and Conanicut island. Amer. Jour. Sci., March, 1897, p. 230. Crosby gives a good bibliography and résumé of previous work.

‡ J. F. Kemp: An orbicular granite from Quonochontaug beach, Rhode Island. Trans. New York Acad. Sci., vol. xiii, 1894, p. 140.

Company and the New England Company. In the quarryman's classification there are minor varieties, such as blue and gray, but petrographically they are practically the same. This is the stone most distinctively known as Westerly granite. It shows the characteristic shelly joints of granites to a remarkable degree (see plate 36, figure 1). In the hill or ridge north of the railway there are a number of other quarries, some of which yield gray granite and some red. The red is much coarser than the gray in crystallization, but is still finer than the Stony Creek red granite, to be later described. It is a rather light shade for a red granite.

Between Niantic and Westerly are other small quarries, which yield gray granites. To the west, in the town of Mystic, Connecticut, there are various small openings, displaying gray granites, and on Masons island, in Mystic harbor, a large ledge has been utilized for rough stone for breakwaters. It is a gneiss, plentifully seamed with pegmatite and aplite dikes, but it shows some quite massive phases. In the town of Groton, near New London, but east of the Thames, are exposures of gray granite, somewhat coarser than the Westerly variety, but of the same general character. Southwest of New London, in the town of Waterford, there is another small quarry. The largest opening in this immediate district is, however, the one on Millstone point, 5 miles west of New London. A neck of rock juts out into the sound and consists almost entirely of granite. The stone is a gray variety, darker than the Westerly stone, but in other respects much like it. The gneisses are visible in the walls of the pit and the contact is an irruptive one. The exposures of granite are shown in plate 36, figure 2.

Quarries for stone for government breakwaters have been opened near South Lyme in gneiss. They have exposed most interesting pegmatites, that have yielded some rare minerals. On the east bank of the Connecticut river, and just north of Lyme station, a coarsely crystalline, pink, porphyritic granite has been developed to some extent in former years. It is a very beautiful stone when polished, but is now no longer worked. Its microcline was studied as long ago as 1880 by Descloiseaux, who has left a brief note on record about it, as is later noted. This granite borders closely on the pegmatites. Passing westward across the Connecticut river, gneisses appear in all the railway cuts until Sachems head, Leets island, and Stony creek are reached. At all of these localities quarries have been opened, but those at Stony creek are the most extensive. The characteristic Stony Creek stone is a coarsely crystalline red variety, that is chiefly obtained north of the station in two large works. One of the quarries is illustrated by plate 37, figure 1. It is extremely massive. South of the station the Brooklyn quarry yields a gray stone, quite finely crystalline, and unique among the granites of the region in that it con-

FIGURE 1.—EASTERN QUARRY OF THE SMITH GRANITE COMPANY AT WESTERLY, RHODE ISLAND

The view shows the onion-like joints

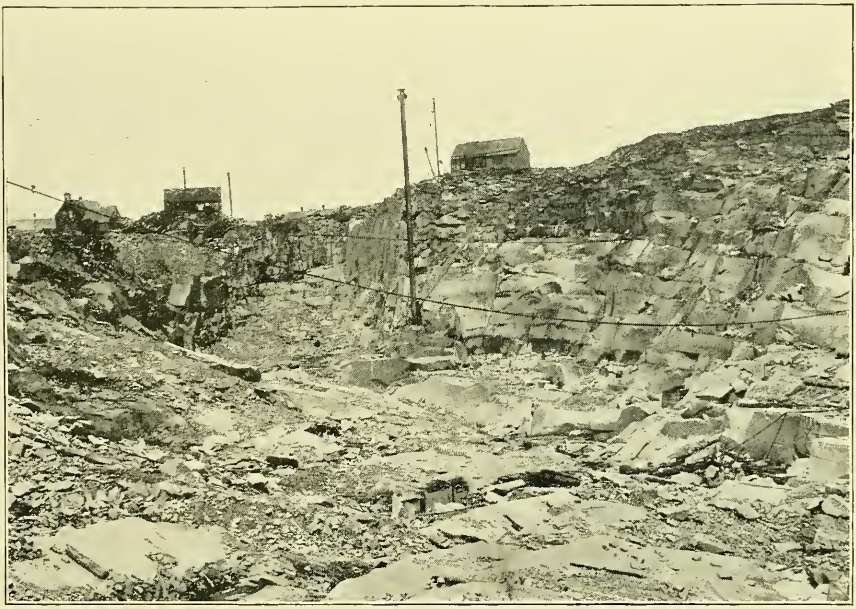

FIGURE 2.—GRANITE QUARRY AT MILLSTONE POINT, CONNECTICUT

GRANITE QUARRIES IN RHODE ISLAND AND CONNECTICUT

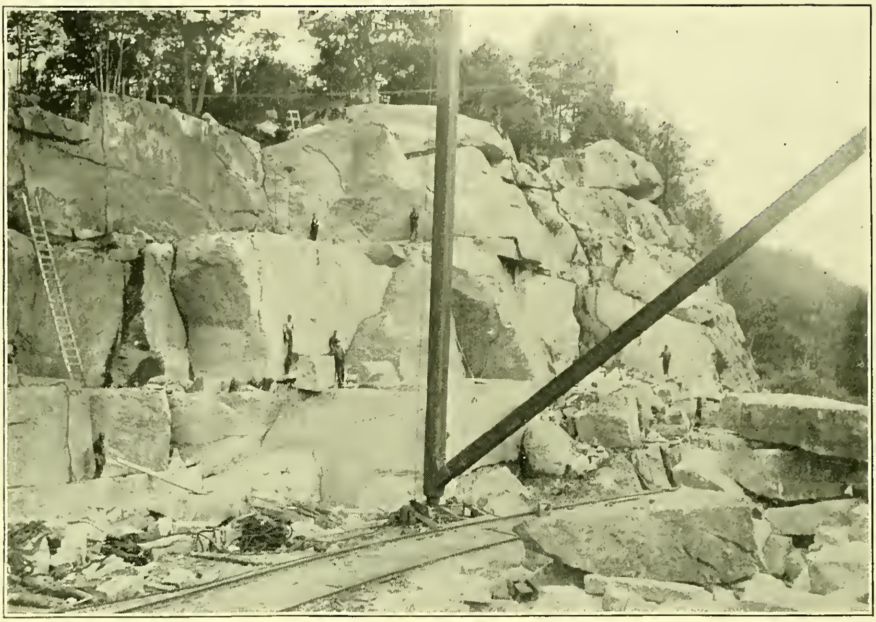

FIGURE 1.—GRANITE QUARRY OF NORCROSS BROTHERS AT STONY CREEK, CONNECTICUT

Showing massive character of the stone and absence of joints, as shown in plate 36, figure 1

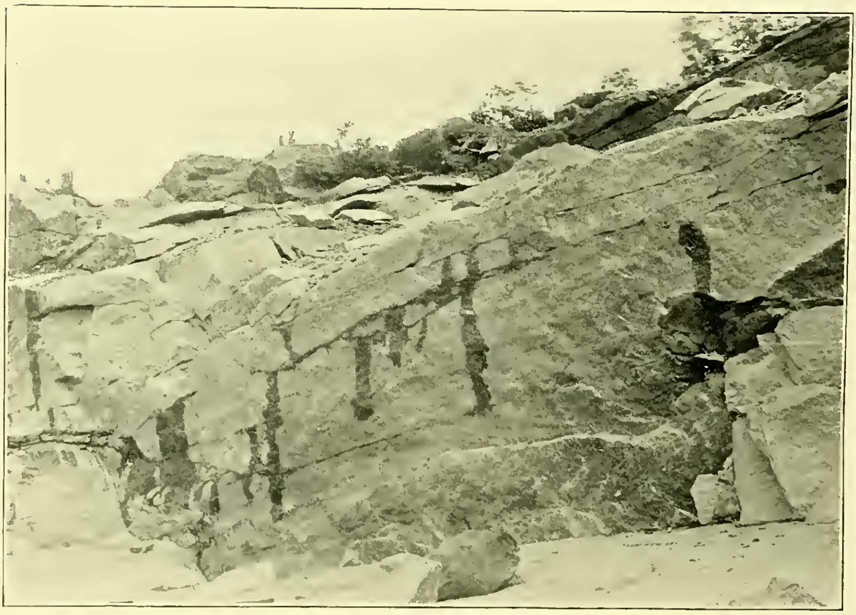

FIGURE 2.—GRANITE QUARRY AT LEETS ISLAND, CONNECTICUT

Showing at left and right basic inclusions. The dark vertical strips are wet places, but the horizontal black strips are inclusions of hornblende-gneiss. The left one is about 8 feet long

GRANITE QUARRIES IN CONNECTICUT

tains numerous garnets. The Leets Island quarries, north of the station, supply a red granite, as do those at Sachems head. An exposure of the former, with basic inclusions, is shown on plate 37, figure 2. Gneissoid varieties of the same are obtained on Hoadlys point, south of the station at Leets island, and the workings are very extensive. The stone is, however, chiefly used for bridge piers. Some small outlying exposures near Leets Island station yield gray granite.

PETROGRAPHY

General characteristics.—All the granites are biotite granites, muscovite, though present, being very subordinate and hornblende failing entirely. They will be described under these types: The Westerly gray, the Westerly red, the Stony Creek red, the Stony Creek gray, the Lyme pink. A brief mention will be made of the Quonochontaug orbicular variety.

The Westerly gray granite.—The Westerly gray variety consists of anhedra of an average size of from 0.5 to 1.0 millimeter. The principal minerals are quartz, orthoclase, microcline, plagioclase near oligoclase, brown biotite, a little muscovite, magnetite, zircon, apatite, and some uncommon accessories. The ones mentioned are, except the last, the normal minerals in granite, and they are so familiar that extended details would be the iteration of elementary phenomena. The quartz has abundant needles of rutile and cavities with bubbles. It contains zircons which show the combinations I and II. The quartz is sometimes included in the feldspar and exhibits tendencies to develop micropegmatites with it. The period of formation of the quartz clearly began before that of the feldspar closed. The orthoclase is sometimes kaolinized and is again water-clear. Zonal growth and Carlsbad twins are both present. Microcline varies in quantity, but may be very abundant. The plagioclase is inferior in amount to the potash feldspars, and as a rule affords very low extinction angles in basal sections. These facts would indicate oligoclase, and the presence of considerable lime in the analyses tends to corroborate the inference. The biotite is deep brown and strongly pleochroic. It bleaches to green on alteration, and has muscovite occasionally associated with it. The biotite is almost always in irregular shreds, but instances have been met in which it is drawn out into elongated parallelograms with good crystallographic boundaries. Its relative abundance is shown in plate 38, figure 1. The magnetite and apatite present no noteworthy features. The other accessories, some of which are of special interest, will be referred to after mention has been made of the red variety of the Westerly granite.

The Millstone Point granite closely resembles the Westerly gray in appearance, but it has less of a bluish cast. It is of about the same grain and does not differ essentially from the type, except, perhaps, in the greater abundance of microcline. Quartz, microcline, orthoclase, oligoclase, biotite, pyrite, and the usual accessories make it up.

The granites from Groton and from the immediate neighborhood of New London all vary but slightly from the type of the Westerly gray. In one from a quarry a mile south of the little station of Waterford, on the Shore Line railroad, just east of New London, the quartzes are charged with twisted blades of some unknown mineral, having the form of Archimedes screws, of very long pitch. Rutile needles, fluid inclusions, and the usual microscopic phenomena of the quartz of granites are universal, but these spirals have not been seen elsewhere.

The Westerly red granite.—The Westerly red granite does not differ essentially in mineralogy from the gray type, although it bears no resemblance to it in the hand specimen. The former is much more coarsely crystalline, the anhedra ranging from 1.5 to 5 millimeters. The orthoclase has a pronounced pink color, which, however, disappears in thin-section. Microcline, oligoclase, biotite, a little muscovite, magnetite, zircons, and apatite are all present.

Accessory minerals in the Westerly granites.—Accessory minerals of a less common character have been recorded already in the Westerly granites by several observers. Iddings and Cross* mentioned allanite in 1885. The writer has also noted it in a hand specimen that attracted his attention because it was spotted with apparent blemishes or stains. The discolorations spread from a dark nucleus, and in thin-section are a yellowish decomposition product that has stained the neighboring quartz and feldspar. The dark nucleus was in one case yellow and afforded aggregate polarization; in another it was pleochroic, dark brown to light brown, biaxial, and of feeble polarization. All these colors correspond with allanite, but as all petrographers familiar with allanite know, in its altered condition it is a very unsatisfactory subject. In a slide from Millstone point zonal allanite was noted exactly like that figured by Keyes,† but not associated with epidote. In 1891 O. A. Derby ‡ described monazite in heavy concentrates from a specimen of the Westerly red variety that was given him by the writer. In a thin-section of a specimen of gray granite from the Miller quarry, Westerly, and near its contact with the gneiss, the writer has met a yellow, doubly refracting mineral which gives a positive uniaxial figure and which is intimately associated with

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*J. P. Iddings and Whitman Cross: Widespread occurrence of allanite as an accessory constituent in many rocks. Amer. Jour. Sci., Aug., 1885, p. 108.

†C. R. Keyes: The origin and relations of central Maryland granites. XV Ann. Rep. Director U. S. Geol. Survey, 1895, plate xxxviii, fig. 4.

‡O. A. Derby: Occurrence of xenotime as an accessory element in rocks. Amer. Jour. Sci., April, 1891, p. 311.

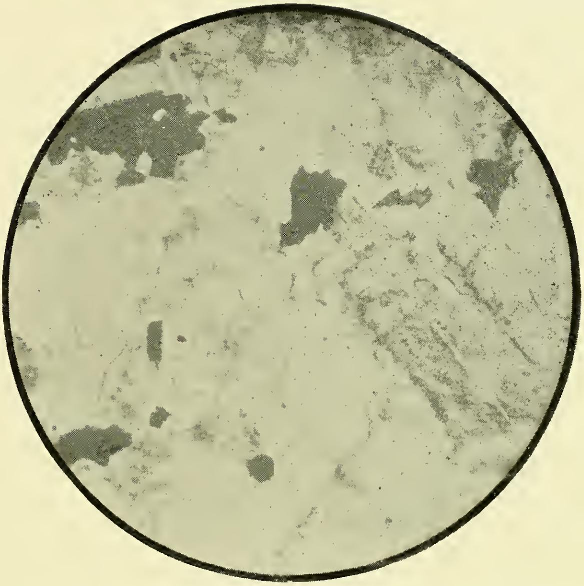

FIGURE 1.—PHOTOMICROGRAPH OF WESTERLY GRAY GRANITE

The dark material is biotite and its relative abundance is illustrated. Actual diameter, 4 millimeters

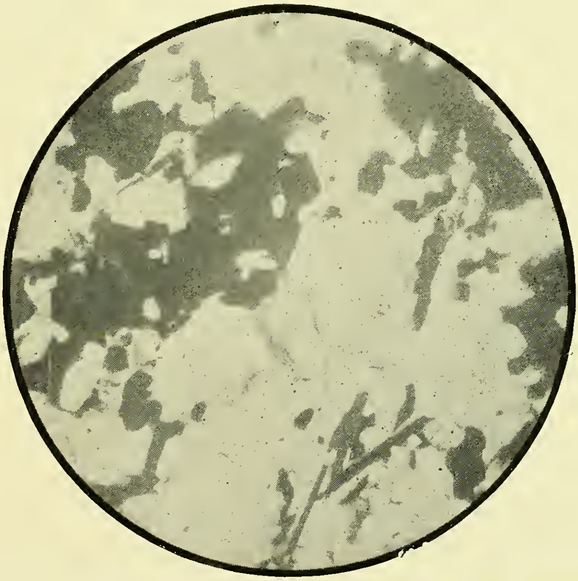

FIGURE 2.—PHOTOMICROGRAPH OF HORNBLENDE-GNEISS FOUND NEAR WESTERLY

The solid, dark material is hornblende. The narrow dark strips are biotite. Actual diameter, 4 millimeters

PHOTOMICROGRAPHS OF GRANITE AND GNEISS

biotite. It is regarded as xenotime, which mineral Derby has shown by concentrates to be widespread in many granites in Brazil. In some general notes on the microscopic characters of biotite granites, G. P. Merrill* remarked, in 1885, the richness of the Westerly granites in accessory minerals, and mentions fluorspar, sphene, menaccanite, magnetite, apatite, epidote, and pyrite. The writer has also noted one or two irregular bits of tourmaline in close association with biotite. Beryl is recorded from Westerly,† but it probably came from a pegmatite dike. Many of these accessories are strongly suggestive of the presence of mineralizers in the magma, and the remarks later made on the pegmatites at Westerly would tend to corroborate the inference.

Quonochontaug orbicular granite.—The interesting orbicular granite at Quonochontaug beach is a peculiar variation of the Westerly gray type. It is associated with a massive variety that is much coarser than the gray granite just described, but does not otherwise differ from it in mineralogy. The details of the spheroids ‡ have been set forth in the original citation which is given above, page 365.

The Stony Creek types.—The granites at Stony creek are of two varieties. One, the Stony Creek red, is the characteristic building stone from this locality. It is a coarsely crystalline rock that is in strong contrast with the other types. The other, the Stony Creek gray, is obtained only from the Brooklyn quarry. It is a more finely crystalline variety than the last named, and has abundant garnets scattered through it, affording thus the only instance of garnet met in the granites. Both these stones have been extensively quarried, the former, however, more largely than the latter.

The Stony Creek red granite consists chiefly of large red microclines which give it its characteristic shade. They average more than 10 millimeters in diameter under the microscope, are clear and but slightly kaolinized. Quartz is abundant and oligoclase of a greenish white is in variable quantity. It may sink to a small percentage, as is indicated by the analysis by Professor L. P. Kinnicut later quoted. A little biotite is present, but it is not specially notable in the stone. There is a little magnetite, and many zircons may be detected with the microscope. In pol-

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* G. P. Merrill: Report of building stones. Tenth Census, vol. x, p. 20.

† A pamphlet entitled "Geology of Rhode Island," which was issued by the Franklin Society of Providence in 1887, has but recently become accessible to the writer. It contains a list of minerals found at Westerly (p. 92) which embraces the following: "Feldspar crystals, micas, quartz, amethyst, pyrite, ilmenite, beryl, garnet." While the pamphlet is largely a compilation, it gives a very complete bibliography on the geology of the state and many notes of local interest.

‡ The writer has recently discovered that this peculiar granite is also mentioned in the report to the Franklin Society cited in the last reference and that a cut of the granite is there reproduced (see plate III and page 92.) The rock is regarded not unnaturally as "a kind of concretionary conglomerate."

ished columns or hammered blocks the granite exhibits a fluidal arrangement of the components that is strongly suggestive of the flow phenomena in porphyritic rocks, and yet it is most probably the result of plasticity induced by pressure. The strength of this conclusion is increased by the pronounced gneissoid phase of this rock that is the basis of the large quarry industry on Hoadlys point just south of the Leets Island station and a mile or two east of Stony creek. This coarse, red gneiss is certainly a phase of the Stony Creek red, and it assuredly owes its foliated character to dynamic metamorphism. Under the microscope the quartzes are crushed and strained, the orthoclases have undulatory extinction, microcline is abundant, and the biotite is dragged out into streaks whose origin is very apparent. These results of squeezing are much more pronounced at Hoadlys point than at Stony creek and the easing of the pressure must have been especially accomplished at the former locality.

The Stony Creek red shows some pronounced pegmatitic developments in the midst of the normal grain, but the constituent minerals do not appear to vary much, except in the introduction of pyrite, which may be quite noticeable.

The Stony Creek gray variety is more finely crystalline than the preceding and contains more plagioclase, which being of a white color makes the general effect of the rock lighter. The analyses, as later shown, are also somewhat contrasted. The component minerals are quartz, orthoclase, microcline, oligoclase, a little biotite, magnetite, apatite, zircons, and large garnets, 10 millimeters in diameter, which produce red spots throughout the general mass of the stone. In thin-section the garnets show no regular outlines, but are irregularly ramifying anhedra. Effects of strain are frequent in the rock and it has evidently suffered from dynamic metamorphism.

INTRUSIVE NATURE OF THE GRANITES

The contacts.—In all cases where the contacts of the granites and the gneisses are visible they are, in the opinion of the writer, plainly irruptive. Although the mineralogy of the two rocks is so nearly the same, it is possible to distinguish clearly between the massive and the foliated individuals. Nearly all of the quarries show these phenomena, but they are especially well exhibited in the quarries south of the railway, at Westerly, at Millstone point, and in the Brooklyn quarry at Stony creek. The granites tongue out irregularly into the gneiss, precisely as if they had been intruded into a shattered country rock, which, however, must have been itself sufficiently hot to have had no perceptible chilling effect on the intrusion. Fragments of gneiss are found in the granite, especially at Millstone point. These mixtures of gneiss and granite and

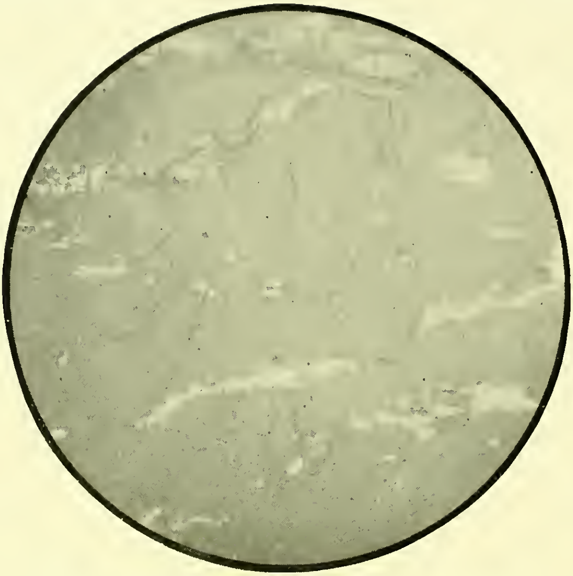

FIGURE 1.—PHOTOMICROGRAPH OF A THIN-SECTION OF ORTHOCLASE

Cut parallel with basal pinacoid to show infiltration of secondary albite along the prismatic cleavage. Actual diameter, 2.5 millimeters, crossed nicols

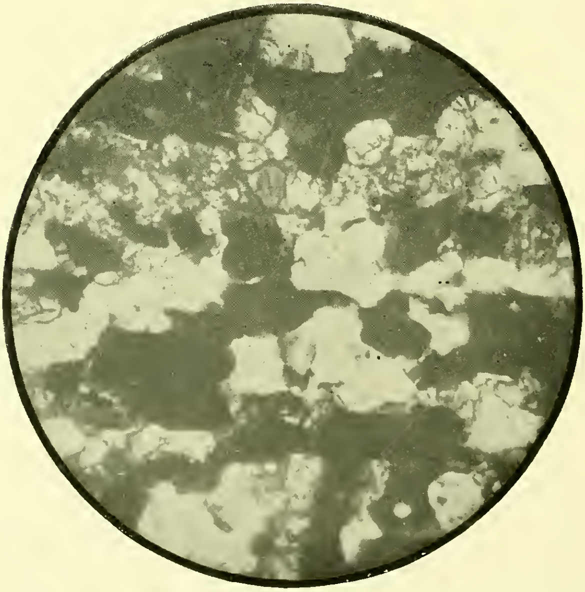

FIGURE 2.—PHOTOMICROGRAPH OF A THIN-SECTION OF BASIC INCLUSION

Piece taken from left hand inclusion in the granite shown in plate 38, figure 2. Dark mineral is hornblende, the shaded one plagioclase, and the white one quartz. Actual diameter, 4 millimeters.

PHOTOMICROGRAPHS OF ORTHOCLASE AND BASIC INCLUSION IN GRANITE the associated pegmatites are the bane of the quarryman and necessitate much dead work and much waste.

The basic inclusions.—A second and very strong form of evidence of the irruptive nature of the granite is furnished by the inclusions of dark basic rock, which are met in almost all the quarries. The inclusions are of two kinds. The first, which consists chiefly of biotite with subordinate orthoclase, plagioclase, quartz, apatite, and magnetite, shows no foliation and is apparently a basic segregation from the magma. It has merely the minerals of the granite with the biotite in great excess. The other is a distinctly foliated, hornblende schist or amphibolite and presents long slabs, which are precisely like the hornblendic schists, occuring in the country rock. A particularly fine example was exposed in 1895 in the quarry north of the railway station at Leets island. It was a dark slab, about 8 feet long and a foot thick. Marked foliation ran its entire length. It was black and in strong contrast with the red granite that held it. A photomicrograph of a thin-section is shown in plate 39, figure 2. Twenty feet away was another included mass, a block about 4 feet in diameter. Around the edges of the inclusions there were several inches of coarse pegmatite before the normal granite was met. This pegmatite border has been noted a number of times and is one of the features of the foreign inclusions. Mineralizers have apparently gathered in special amount around the included mass and have caused the large feldspars and quartz to develop. Under the microscope the slab-like inclusion from Leets island was found to be chiefly hornblende, with which was associated considerable biotite, plagioclase, scapolite, titanite, magnetite, and a little quartz. This assemblage is that of a typical hornblende schist. A basic inclusion in the granite of the Brooklyn quarry, at Stony creek, was found to have undergone alteration and to have yielded red rhombohedra of chabazite.

These inclusions correspond closely to the basic country rock, and there seems no reasonable explanation for them other than that they have been torn off from these originals during the intrusion of the granite.

Some special emphasis is placed on the intruded character of the granites because they have been regarded as extreme phases in the metamorphism which in its incomplete development has produced the gneisses. Although nowhere stated in so many words, the late Professor Dana seems to imply this view in his interesting geological guide book to the environs of New Haven.* The writer hesitates to differ with so respected and generally beloved an authority as Professor Dana, but in this particular he only reflected the prevailing views of an earlier

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*J. D. Dana: The four rocks. New Haven, 1891, p. 118. Professor Dana did not overlook the effects of dynamic metamorphism, but does not consider the granites irruptive.

generation on the significance of foliation in metamorphic rocks. The widespread foliation of the country rocks in the region under consideration antedates the intrusion of the granites, which, although not entirely, yet in most instances, escaped notable dynamic metamorphism. As already stated in the introductory sketch, granites of post-Cambrian, if not of post-Carboniferous, age are recognizable at Newport and Conanicut island, which have penetrated wall-rocks already highly metamorphosed. The granites have themselves, then, suffered the effects of pressure, and in the absence of positive evidence to the contrary we may not be certain that the more western intrusions in Rhode Island and Connecticut are not of the same age—that is, at least post-Cambrian. They assuredly are pre-Triassic.

The Aplites and the Pegmatites

Aplite dikes of a small thickness are frequently met and are plainly of an intrusive nature. They cut the gneisses regardless of their foliation, and are to be considered as minor border phenomena around the granites. The chief constituent minerals are quartz and orthoclase. Biotite, muscovite, microcline, and acid plagioclase are all in subordinate amount.

The pegmatites are present in great numbers and at times attain very considerable size. They cut the gneisses as dikes of varying width, and are beyond question genetically connected with the granites. The pegmatites vary from those of granitic mineralogy to those that are practically pure quartz.* They are specially abundant along the west coast of Narragansett bay, as shown in plate 40, figures 2 and 3.

The commonest kind is a very coarse aggregate of red microcline, white natron-orthoclase, albite, and quartz, together with a little black, brittle biotite and occasional thin plates of ilmenite and masses of magnetite. The microcline is flesh-red and exhibits crystals that almost always have some recognizable faces and that may be beautifully developed. An exposure of one of the pegmatites is illustrated by plate 41, figure 1. The simplest and commonest combination contains l (110), M (010), P (001), x ($\bar{1}01$), or y ($\bar{2}01$), and z (130). The crystals are either equally developed along each axis or else are drawn out on the vertical axis into a prismatic elongation. One specially perfect one which was obtained by chiseling away the surrounding quartz at the Smith quarry, Westerly, exhibits the above faces, and in addition o ($\bar{1}11$), and n (021). Carlsbad twins have been found, but are not particularly common. Manebacher twins are quite as frequently seen, and in several instances have been

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* Professor J. D. Dana states in "The four rocks," p. 116, that the quartz veins are later than the granite veins; *i. e.*, than the pegmatites, as the former cut the latter when both occur together.

FIGURE 1.—VEIN OF BLACK BIOTITE AND GARNET

In granites of Masons island, Mystic harbor. Vein is vertical in the quarry and is 2 inches wide

FIGURE 2.—PEGMATITE DIKES

Cutting Cambrian schists, near Watson's pier, west side of Narragansett bay

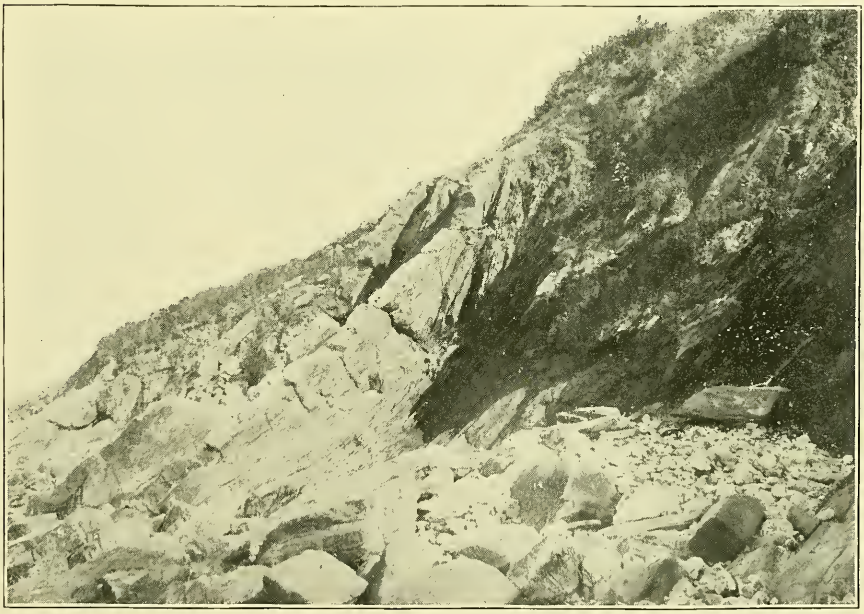

FIGURE 3.—NEAR VIEW OF TWO OF THE PEGMATITE VEINS SHOWN IN FIGURE 2

PEGMATITE VEINS AND DIKES, AND VEIN OF BIOTITE AND GARNET

collected of notable perfection. This flesh-red microcline was taken for orthoclase in the field, and at first sight one would consider it a typical case of the latter, but the moment flakes are tested with polarized light, the peculiar twinning and extinction angles of microcline may be readily recognized. The latter is about 15 degrees on the basal flakes and 5 degrees on the brachy-pinacoidal. The specific gravity, as determined on pieces of from 15 to 20 grams, is 2.532 to 2.539—values that are from 0.02 to 0.03 below the general average of microcline.

A white feldspar is widely associated with the red microcline and is of especial excellence in the Westerly quarries. It is automorphic, but must be dug out of the quartz that fills the interstices of the feldspar crystals. The crystals are well developed and can be obtained at times with fairly perfect terminations, although as a rule they have interfered one with another in growth. The base is striated, so that in the field they were all taken for albite.

Optical tests of some cleavage flakes parallel with the base at once revealed an extinction angle of zero degrees, while other flakes parallel with the brachy-pinacoid gave one of 9 degrees. The specific gravity on one lot was found to be 2.595, and on another 2.613. The latter value approximates albite, but the optical properties were those of natron-orthoclase. A positive bisectrix emerges nearly perpendicularly to the brachy-pinacoid. The crystals exhibit, as determined by the eye alone, P (001), M (010), T ($1\bar{1}0$), l (110), x ($\bar{1}01$), y ($\bar{2}01$), n ($0\bar{2}1$), and o ($11\bar{1}$). The faces n and y are dull, but the others are quite bright. Between y and P there are two other domes on one crystal, of which one is doubtless x.

It is probable that both albite and natron-orthoclase are present, and some quantitative chemical tests corroborated this view, although they were not complete enough for an analysis.

In a large crystal, partly microcline and partly orthoclase, from a pegmatite vein on Masons island, Mystic, Connecticut, weathered surfaces were found running roughly parallel with a somewhat imperfect cleavage, which is itself parallel with the prism faces. The weathered surface was thickly set with little crystals of secondary feldspar whose vertical axis, basal pinacoid, and prism faces are parallel with those of the host. The former are white, while the latter is red. The former are striated on the base. As a maximum they are 1.5 millimeters in length and vary from this down to extreme minuteness. The twinning which they exhibit in thin sections parallel with the base makes it evident that they are a plagioclase near albite. These secondary feldspars are clearly infiltration products that have come in along the prismatic cleavage cracks, and especially the ones parallel with the right-hand prism face. One can not well say, however, at what stage in the history of the rock they entered, but they are significant as bearing on the general production of microperthites. A section parallel with the basal pinacoid is illustrated in plate 39, figure 1. In this connection it is interesting to note that Descloiseaux remarked the presence of inclusions of albite in a specimen of microcline from the McCurdy quarry at Lyme, but he speaks of them as being extremely minute.*

One microcline crystal, about 6 inches on each axis, quite perfectly developed and doubly terminated, although attached at the end of the a-axis, was obtained on Masons island.

The biotite of the pegmatites is a brownish green and is strongly biaxial. One small vein of it and garnet was found on Masons island, Mystic, as is illustrated in plate 40, figure 1. It is a rather brittle variety. The quartz was the last of the chief components to crystallize and forms a brittle, interstitial filling, not otherwise noteworthy. The ilmenite occurs in tabular crystals varying in thickness up to 6 millimeters. The flattening is parallel with the base. One rhombohedron was noted, but it was too rough for sharp determination. Apatite has been discovered once, and that on Masons island. The crystal is bounded by the hexagonal prisms of the first and second orders, but is not terminated by faces. Tourmaline is rare in the pegmatites all along this portion of the sound, although it is abundant farther west. Only once was it noted, and that was at Millstone point. Molybdenite is very abundant in a pegmatite that is exposed in a railway cut just east of South Lyme. It forms large flakes, sometimes a square inch in area, and is thickly set in the rock. In the neighboring quarry, on the other side of the track, the exceptionally good monazite crystals were discovered which have been described by W. D. Matthew.† They specially favor the large leäves of biotite and occur closely packed in under the latter. This association facilitates their discovery, for they are rare at best. Matthew also figures one of the manebacher twins of microcline, regarding it as orthoclase.

The only other minerals which have been noted in the pegmatites are magnetite and muscovite. The former exhibits the usual lamellar planes of growth parallel to the octahedron, and the latter is in no way noteworthy.

The proportions of the several minerals in the pegmatites vary considerably, but in the normal specimens one might say that red microcline is most abundant and makes up about 50 per cent of the whole. Natron-orthoclase and albite follow with about 25 per cent, then quartz with perhaps 20 per cent, leaving 5 per cent for all the rest. Quartz

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*American Journal of Science, October, 1880, p. 335.

†W. D. Matthew: Monazite and orthoclase from South Lyme, Connecticut. School of Mines Quarterly, April, 1895, p. 231.

Figure 1.—Pegmatite Dike exposed at South Lyme, Connecticut

The large crystals of microcline are indicated

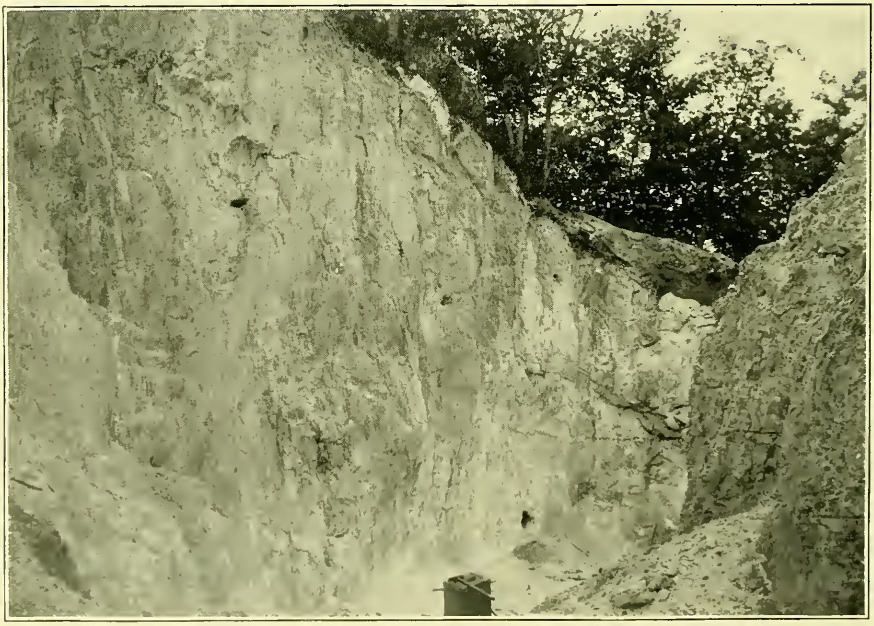

Figure 2.—View in the "Silex" Mine

This mine is based on the pulverulent quartz at Lantern Hill, Mystic. The banded structure of the quartz is clearly shown

PEGMATITE DIKE AND "SILEX" MINE

may, however, become much more abundant, and instances have been met, as in a large vein near Sachems head, which consists of quartz with but a few feldspar crystals distributed through it. An extreme development of pure quartz is also known, and to this latter variety must be referred the huge quartz vein that forms Lantern hill, north of Mystic. Lantern hill is the highest elevation in this part of Connecticut and is a landmark for sailors. The vein is several hundred feet across and is certainly a deposit from solution, as its quartz crystals are in banded arrangement; they interlock and exhibit the characteristic features or "crustification" of a typical mineral vein. At the north end the vein is hard, massive quartz, but at the south end it is so pulverulent that it can be dug with a pick and shovel and can even be crumbled with the fingers. Its pulverulent character has been referred by the writer to crushing.* It is illustrated by plate 41, figure 2. As earlier stated, Professor Dana observed that the quartz veins near Stony creek were later than the pegmatites, and it may well be that they mark the closing and fumarolic stages of the intrusive phenomena.

CHEMICAL COMPOSITION OF THE GRANITES

The following analyses † will give a fair idea of the ranges in composition of the granites which have been described above:

	I.	II.	III.	IV.	V.	VI.
	Conanicut island.	Westerly gray.	Westerly red.	Millstone point.	Red Granite Company, Stony creek.	Brooklyn quarry, Stony creek.
SiO_2	71.23	71.64	73.05	68.40	72.73	72.06
TiO_2	0.21	....	....	....	....	....
Al_2O_3	13.64	15.66	14.53	15.75	16.95	14.83
Fe_2O_3	1.70	2.34	2.96	2.972		1.28
FeO	1.00			0.649		0.64
MnO	0.05	Tr.	Tr.	Tr.	....	Tr.
CaO	2.31	2.70	2.06	1.64	1.05	1.20
MgO	0.75	Tr.	Tr.	0.12	Tr.	0.13
K_2O	3.79	5.6	5.39	5.78	8.15	5.64
Na_2O	3.55	1.578	1.72	4.16	0.90	4.31
S	....	....	....	0.626	....	0.12
H_2O	1.72	0.482	0.29	0.48	0.22	0.65
Total	99.95	100.00	100.00	100.577	100.00	100.86
Sp. gr.	2.69					

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* J. F. Kemp in Transactions of the New York Academy of Sciences, May 18, 1896, vol. xv, p. 189.

† The writer takes this opportunity to express his thanks to Doctors Love and Vulté for the above analyses, which they have been so kind as to make for him.

I. Epidotic granite. By L. V. Pirsson. American Journal of Science, November, 1893, page 373.

II and III. By F. W. Love, formerly Instructor in Chemistry, Cornell University The analyses were made for this paper some years ago. On account of the accidental loss of the solution in which the mixed alkaline chlorides were to have been determined, the soda was estimated by difference. The potash was directly weighed.

IV. By H. T. Vulté, Instructor in Chemistry in Barnard College, Columbia University. This analysis and VI were made for this paper.

V. By L. P. Kinnicut, of the Worcester Polytechnic Institute, for the Red Granite Company, from whom it was obtained.

VI. By H. T. Vulté.

Specific gravities of samples different from those on which the analyses have been based have been determined as indicated below. Samples of from 100 to 800 grams were employed, and where possible polished specimens were used:

Westerly, gray variety	2.654	
Millstone point	2.660	2.671
Stony point, Norcross quarry, finer grain	2.626	Coarser, 2.634
Stony point, Brooklyn quarry	2.640	2.650
Leets island, gneissoid	2.649	
Stony creek, mica-gneiss	2.704	
Masons island, aplite	2.596	
Masons island, basic inclusion	2.860	
Stony creek, basic inclusion	2.987	
Stony creek, basic inclusion	2.880	
Stony creek, basic inclusion (Brooklyn quarry)	2.957	

An examination of the analyses brings out the fact that, except for the one from Millstone point, the granites have quite uniform percentages of silica. The ones from Rhode Island range somewhat higher in lime than do those from Connecticut. The magnesia is very low except in the one from Conanicut. In the relations of the alkalies there are some interesting contrasts. In I, IV, and VI the soda is relatively high. In II and III a very decided preponderance of the orthoclase molecule is indicated, and in the sample used for V there must have been a great excess of orthoclase or microcline. The analysis would indicate one of the purest orthoclase (or microcline) granites of which any record has been made. While samples may be obtained in the quarries which fulfill this requirement, the general run of the stone contains more oligoclase.

General Remarks on the Granites of the Atlantic Seaboard

STATISTICS OF VARIETIES

All persons familiar with either the rocks or the quarry industry of the Atlantic states are aware that granites are exceedingly abundant throughout the region. In the maritime provinces of Canada they are likewise present in vast amount. In southern Nova Scotia the slates and schists of supposed Algonkian age are penetrated by them, and exhibit zones of contact metamorphism.* In New Brunswick, both along the immediate coast and in the interior, granites are known to exist in abundance, and in some instances to be as late as the Devonian.† Throughout New England and the crystalline areas of the states to the south, granites are among the most common rocks.‡ While they have suffered much from dynamic metamorphism in one place and another, yet there are many that are still massive and that are typical eruptives. They are so often situated near tidewater, or else they possess such other advantages for economical transportation, that they have been very extensively utilized for building stone. As a result, they have been widely distributed, and in most cases have been already determined with the microscope and recorded in the reports on building stone which have been especially prepared by G. P. Merrill.§ The writer has also had his attention directed to the same subject in connection with lectures to students in courses on architecture, and has had the opportunity to study the Tenth Census collection of cubes which is exhibited in the American Museum of Natural History, New York. Considerable experience has likewise been gained in the field.

The preponderance of biotite granites in this portion of North America is very striking, as will be seen from the following tabulation, which is

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* J. E. Woodman: Studies in the gold-bearing slates of Nova Scotia. Proceedings of the Boston Society of Natural History, vol. xxviii, pp. 375–407; especially 392. Mr Woodman gives a valuable bibliography.

† Bailey and Matthew, in Annual Report of the Geological Survey of Canada for 1871, p. 180.

‡ An excellent review of these, with a bibliography, will be found in the paper by George H. Williams on "The general relations of the granitic rocks in the middle Atlantic Piedmont plateau." It is far from the writer's purpose in the present paper to repeat any of the points set forth in the admirable survey of these eruptives that is presented by Doctor Williams, whose intention in writing his paper was clearly to demonstrate their abundance, to record what was known of their eruptive character, and upon this to base an argument for the eruptive nature of many of the gneisses in the great crystalline complex. The particular petrographic characters of the granites outside of Maryland receive but passing mention, and it is the purpose here to emphasize their remarkable uniformity.

§ G. P. Merrill, in Tenth Census Reports, vol. x, pp. 52–77.

based on the statistics of the Tenth Census and on several papers which have appeared since 1885 and which are cited in the foot-notes:

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
Maine........	56	2	7	1	2	1	......	......	......	....
New Hampshire.	17	......	17	2	5	5	1	2	......	....
Vermont........	9	......	3	......	......	......	1	......	......	....
Connecticut.....	9	6	2	1	8	......	......	......	......	....
Massachusetts...	6	2	2	3	2	6	......	......	1	....
Rhode Island...	6	1	......	......	......	......	......	......	1	....
New York......	......	1	......	......	3	1	......	......	......	1
Pennsylvania...	1	1	......	2	......	......	......	......	......	2
Maryland.......	5	......	1	......	1	......	......	5	......	....
Virginia......	6	2	1	......	......	......	......	......	......	....
Georgia.........	......	......	2	......	......	......	......	......	......	....
Totals....	115	15	35	9	21	13	2	7	2	3

Of North Carolina and South Carolina no statistics are available.

I, biotite-granite; II, biotite-gneiss; III, muscovite-biotite-granite; IV, muscovite-biotite-gneiss; V, biotite-hornblende-granite or gneiss; VI, hornblende-granite; VII, muscovite-granite; VIII, biotite-epidote-granite or gneiss; IX, epidote-granite; X, hornblende-gneiss.

A survey of these figures brings out strongly the great preponderance of the biotite-granites over the others, and if to the total for the biotite-granites we add also the totals for the biotite-gneisses, the muscovite-biotite-granites and gneisses, and the biotite-epidote-granite or gneiss, a procedure that is practically justifiable, the conclusion is emphasized the more strongly. In fact the occurrence of other granites makes one suspect that more or less abnormal rock-types are present and to infer peculiar conditions. This last feature will be further commented on in the remarks on the several provinces or states which are given below.

REVIEW BY PROVINCES OR STATES

New Brunswick.—Data are not at hand for detailed statistics of New Brunswick, but biotite-granites are not lacking. In addition, W. D. Matthew* has described a dioritic granite from Saint John. It is in close association with gabbro, possibly as a local differentiation product from a single parent magma. Geological descriptions of other areas have been prepared by L. W. Bailey and G. F. Matthew,† and by G. F. Matthew alone.‡

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* W. D. Matthew: The intrusive rocks near Saint John, New Brunswick. Trans. N. Y. Academy of Sciences, vol. xiii, 1894, p. 185.

† Geological Survey of Canada, 1870–'71, p. 180.

‡ Idem., 1876–'77, p. 345.

Maine.—Biotite-granites are especially prominent in Maine, and the figures above given are the more significant because the data are more complete than are those of many of the other states. The quarries in the interior are less developed than are those on the seacoast, and it may be that hornblendic varieties are relatively more abundant away from the ocean. The one hornblende-granite cited in the table occurs at Otter creek, Mount Desert, and, as remarked by G. P. Merrill,* it resembles the red Saint George's hornblende-granite of New Brunswick. The two biotite-hornblende granites of the table are both from Saint George, Knox county. In the southern central part of the state, Doctor Merrill † has already remarked the prevalence of the biotite-granites over all other varieties in Maine.

There is a very considerable literature on the coastal region of Maine, but the petrographical characters of the granites are not often referred to in detail. G. O. Smith, in his valuable paper on the "Geology of the Fox Islands," 1896, p. 60, gives some observations on the rock at Vinal Haven.

New Hampshire.—In the granites of this state muscovite is a frequent associate of biotite, the two micas appearing together about as often as does biotite alone. One hornblendic variety is known at the famous intrusion on Mount Willard, in the Crawford notch, a locality that has been made classic by the work of Hawes.‡ Four or five others are mentioned by Hawes in the New Hampshire report, and about as many more with both biotite and hornblende.

Vermont.—In Vermont the same general relations hold good as in the states just noted. Biotite-granites are now known to occur on Mount Ascutney in association with very acidic augite-syenites of peculiar and rather complex mineralogy.§

Massachusetts.—Hornblende-granites are relatively more prominent in Massachusetts than in any other state of the Atlantic border, because of the peculiar petrographic characters of the rocks to the north and south of Boston. The Quincy hornblende-granite is one of our best known building stones, but its detailed microscopic characters have not received much attention until recently. The presence of the soda-amphibole riebeckite, as finally determined by H. S. Washington, distinguishes it from the ordinary run of granites and suggests connections with

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* G. P. Merrill: On the collection of Maine building stones in the U. S. National Museum. U. S. Nat. Mus. Proceedings, vol. vi, 1883, pp. 178–183.

† G. P. Merrill: Stones for building and decoration, second edition, pp. 236–245.

‡ G. W. Hawes: The Albany granite and its contact-phenomena. Amer. Jour. Sci., Jan., 1881, p. 21. Report on the lithology of New Hampshire. N. H. Geol. Survey, vol. iii, 1878, p. 190.

§ The Ascutney rocks are now under investigation by R. A. Daly. Several analyses have been published (Bull. 148, U. S. Geol. Survey, pp. 68–69), and Mr Daly gave verbally some details of the rocks in the discussion of Professor Cushing's paper, which appears elsewhere in this volume.

the curious assemblage of eruptives that come to the surface on Cape Ann.*

Dr. Washington has called the latter the "Petrographical Province of Essex County," and in this way has emphasized the peculiar characters of the region. The granites in the central part of the state are more like those elsewhere in New England.

Rhode Island and Connecticut.—These states have been sufficiently described in the main part of this paper.

New York.—Only granites in the southeastern part of New York are here considered. A number of intrusions of a more or less pronounced dioritic character have been noted by F. J. H. Merrill and his assistants in the schistose or gneissic rocks of Westchester and New York counties.† Kemp and Hollick have remarked the dioritic character of the granite at mounts Adam and Eve, in Orange county. Some biotite is present in the rock, but it is a minor component. One can not say, in the present state of our knowledge, to what extent intrusive granites may enter into the crystalline complex of the Highlands of the Hudson, but, so far as information is at hand regarding the undoubted eruptive rocks of this section of New York, it may be stated that the granites depart notably from the prevailing biotite-granites of the coast.

New Jersey.—True granites as distinguished from gneisses are not prominent in this state. Some of a more or less pegmatitic nature have been long known in the belt of white crystalline limestone of Sussex county, and Wolff and Brooks ‡ have identified the "Losee Pond granite" as an important member in the pre-Cambrian crystallines lying east of Franklin furnace. It is a binary (that is, quartz and feldspar) granite.§

Pennsylvania.—Pre-Cambrian gneisses are extensively developed in

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*The petrography of the Quincy granite has been set forth in detail by T. G. White in the following paper: "A contribution to the petrography of the Boston Basin." Proc. of the Boston Soc. of Nat. Hist., vol. xxviii, 1897, p. 117. Mr White gives a complete bibliography. Doctor Washington has added an important note on riebeckite: "Soelvsbergite and Tinguaite from Essex county, Massachusetts." Amer. Jour. Sci., August, 1898, p. 180. Doctor Washington's most important contribution to the petrography of the region will be found in a series of papers entitled the "Petrographical province of Essex county, Massachusetts," which began in the Journal of Geology, vol. vi, No. 8, November–December, 1898. A full bibliography is given.

†F. J. H. Merrill: The geology of the crystalline rocks of southeastern New York. Report of the New York State Museum, 1896, p. 30.

H. Ries: On a granite-diorite near Harrison, Westchester county, New York. Trans. N. Y. Acad. Sci., vol. xiv, 1895, p. 80.

J. F. Kemp and Arthur Hollick: The granite at mounts Adam and Eve, Warwick, Orange county, New York, and its contact phenomena. Annals N. Y. Acad. Sci., vol. vii, 1894, p. 638.

‡J. E. Wolff and A. H. Brooks: The age of the Franklin white limestone of Sussex county, New Jersey. XVIII Ann. Rep. Director U. S. Geol. Survey, part ii, p. 431.

§ It is to be regretted that C. R. Keyes and, following him, E. B. Matthews, in the references given below under Maryland, have employed "binary granite" for a granite with both micas. Its use for granites consisting of only quartz and feldspar has been so long established in the older text-books that a change in the meaning only creates confusion.

eastern Pennsylvania, but regarding massive granites little information is recorded.

Maryland.—The granites of Maryland conform quite closely to the biotitic types. They show some variation from them in the presence of epidote in such relations that it is regarded as an original mineral by C. R. Keyes. Biotite is, however, always associated with it. Muscovite-granites are quite uncommon, and varieties with hornblende are noticeably rare. The chemical composition of the Maryland* granites has been more fully investigated than that of other states as yet. Seven analyses in all are available. They vary somewhat widely in the amounts of potash, soda, and lime which are present. In but two cases, namely, Woodstock and Brookville, does the molecular ratio of potash exceed that of soda, and then only slightly. In the others the molecular ratio of the soda is in marked excess, and in the Port Deposit stone it is nearly three times as much In these latter cases the granites exhibit tendencies toward the quartz-mica-diorites.

Virginia.—So far as recorded, the Virginia granites are all of the biotitic type. Both in the hand specimen and in thin-section they resemble the finer-grained, gray biotite-granites of the areas further north.

North Carolina.—Granites are abundant in this state and are quite extensively quarried. The Tenth Census did not, however, tabulate the determinations of them. G. P. Merrill † has given some notes upon their character and distribution, but not always with mention of the mineralogy. Statistics can not, therefore, be compiled, but it is apparent from this record, and the writer has also learned from his colleague, Doctor A. A. Julien, whose acquaintance with the petrography of North Carolina is extensive, that biotite-granites are abundant, and that other varieties are also present.

South Carolina.—Granites are known to occur in South Carolina, but their mineralogic characters are not yet a matter of record.

Georgia.—In two localities in Georgia muscovite-biotite-granites are extensively quarried, Stone mountain and Lithonia. The huge doming ridge of Stone mountain is in fact one of the most striking geological phenomena of the East. Muscovite prevails over biotite in the rock, although the latter is fairly abundant. There are doubtless many other

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*G. H. Williams: The general relations of the granitic rocks of the middle Atlantic Piedmont plateau. XV Ann. Rep. Director U. S. Geol. Survey, 1895, p. 657.

C. R. Keyes: Origin and relations of the central Maryland granites. Idem., p. 685.

G. P. Grimsley: Granite of Cecil county, in northeastern Maryland. Jour. Cincinnati. Soc. Nat. Hist., vol. xvii, 1894, pp. 56–67, 87–114.

E. B. Matthews: Report on Maryland building stones. Maryland Geological Survey, vol. ii, 1898, pp. 136–160. Doctor Matthews also gives an excellent bibliography on p. 131.

† Stones for building and decoration, 1897, pp. 257–260.

granites in the pre-Cambrian complex, but of their particular characters the writer is unable to speak. The same is true of Alabama.

Résumé

In résumé, it may again be emphasized that there is a great and widespread development of granites along the Atlantic coast or near it. The granites have been intruded to our certain knowledge at several different geological periods; but allowing for the considerable variation that is present in some regions, there is a striking predominance of biotite-granites over all others, and among the rest there is a much greater abundance of varieties allied to the biotite-granites than of those, such as pure hornblende-granites, which are in contrast with them.

It is also an impressive fact that throughout much the same region as that which contains the granites, there is a great development of rocks of the gabbro family and of diabases. While the surmise is quite purely speculative the query may be raised as to whether in the long course of geologic time some great parent magma has not given rise to these several fractions, and also as to whether the abundant pre-Cambrian volcanics of rhyolitic nature may not be the effusive products which correspond to some of the deep-seated granites.

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JURASSIC FORMATIONS OF THE BLACK HILLS OF SOUTH DAKOTA*

BY N. H. DARTON

(Read before the Society December 28, 1898)

CONTENTS

FIELD OF INVESTIGATION

During the past two seasons I have been engaged in making a detailed study of the sedimentary formations of a portion of the Black

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hills of South Dakota and Wyoming. The principal observations were made in the southern half of the area, but some atttention was given to the northern extension of the Mesozoic formations. The fossil fish described by Doctor Eastman in his paper, which immediately follows this one, were discovered in 1898 in the Jurassic beds near Hot Springs, South Dakota, near the southern margin of the region.

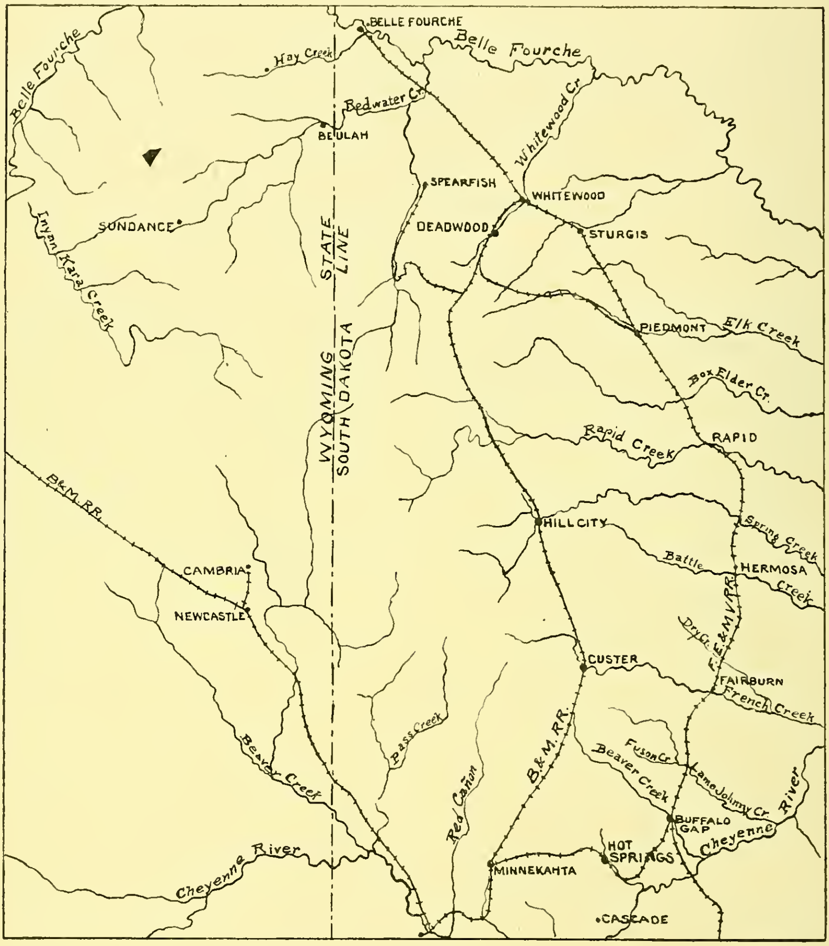

FIGURE 1.—*Outline Map of Black Hills*

GENERAL CHARACTER OF BLACK HILLS

The Black Hills uplift is an irregular dome-shaped anticlinal, having in its more obvious features an oval area 120 miles in length and 60 miles in breadth, with its larger dimension lying nearly northwest and southeast. It is situated in the great east-sloping plain that extends from the Rocky mountains to the Mississippi river. It has brought above the general surface level an area of pre-Cambrian crystalline rocks, now eroded into a small group of mountains, on the flank of which is exhibited a complete sequence of the Paleozoic and Mesozoic rocks from Cambrian to Laramie, all dipping away from the central nucleus. The region is one of exceptionally fine exposures, which afford rare opportunity for a study of stratigraphic relations and variations. The Jurassic beds are seen here for the first time as one goes westward across the United States, and present many features of interest, some of which will be described in the following pages.

Previous Investigations of Black Hills Jurassic Beds

The existence of Jurassic beds in the Black hills was first ascertained by Hayden, who, in 1857, discovered marine fossils which were identified and described by Meek. Hayden's descriptions of the Jurassic beds were meager, and he included in the Jurassic the Red beds, and at one point a limestone with fresh-water fossils which I have recently found to be Tertiary.

N. H. Winchell visited the region in 1874, and in his report recorded a few general facts as to character and distribution of some of the Jurassic beds along his line of travel.

Henry Newton made a very much more extended survey of the Hills in 1875, and in his report added greatly to our knowledge regarding the Jurassic deposits. He described a number of typical exposures in considerable detail, but attempted no classification of the members. His principal statements are as follows:

> "The Jura of the Black hills consists primarily of gray or ash-colored clay or marls, with occasional bands of green and red. Interbedded with these are soft sandstones more or less argillaceous and a few restricted bands of limestone. . . . The thickness . . . is about 200 feet, but it shows a remarkable increase towards the north and northwest, attaining in the Belle Fourche valley a depth of nearly 600 feet. . . . On the north and west and to a less degree to the south the formation is well exposed and characterized by a greater or less abundance of fossils. On the southeast and east it is less plainly seen, being usually covered by a broad talus, and, so far as examined, it was not found to be fossiliferous. . . . It was found impossible to base a subdivision of the formation either on persistent lithological characters or on the distribution of fossil forms. . . . The Jurassic strata . . . are always easily distinguished from the Red beds. . . . Everywhere a large portion of the formation is composed of sandstones which are usually light in color and even sometimes a snowy whiteness."

The upper limit of the Jura is so placed by Newton in most cases as to comprise only the beds containing Jurassic molluscan remains, but in places it includes a greater or less amount of overlying sandstones.

Several years ago O. C. Marsh collected saurian remains from the shales overlying the marine Jurassic beds near Piedmont, on the east side of the Hills. He also obtained through a local collector a large number of cycads from the sandstone near Piedmont and other places which was classified as Dakota by Newton. The saurian remains are Jurassic, but Marsh* has been disposed also to regard the cycads as the same in age.

The cycad-bearing sandstones have been examined by L. F. Ward at several points in the Hills, and W. P. Jenney has collected many plants from coals associated with these sandstones in the northern Hills. It is Ward's † opinion that this flora is Lower Cretaceous.

In 1898 I discovered saurian bones at or near the cycad horizon, at Buffalo gap, as announced to this society in December of that year. Doctor Lucas, who is studying the bones, is not prepared to give a decided opinion as to whether they are early Cretaceous or late Jurassic, but they would usually be regarded as Jurassic; so it is that the upper limit of the Jurassic in the Black hills is perhaps open to question. This, however, need not be discussed in the present paper, as it will be treated by Doctor Lucas and the writer in a later communication.

RELATIONS OF THE BASE OF THE JURASSIC

The base of the Jurassic is clearly defined throughout the area of the Hills by an abrupt change in the character of the sediments, more or less slight erosion, and the evidence of an entirely different history from that of the underlying Red beds. Some features of the Jura-Trias contact are shown in the two figures of plate 44 (page 393).

CLASSIFICATION, COMPOSITION, AND NOMENCLATURE OF BLACK HILLS FORMATIONS

From the result of my recent study it appears desirable to formulate the following classification and nomenclature for the Black Hills Jurassic and adjoining formations:

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*Am. Jour. Science, 4th series, vol. 6, p. 167.

†Journal of Geol., vol. 2, pp. 250–266, and 19th Annual Report U. S. Geological Survey, Part II, pp. 521–958.

Age.	*Formation.*	*Principal components.*
Lower Cretaceous (or Jurassic?)..	Lakota....	Coarse buff sandstones with fire-clays and local coal beds.
	Beulah....	"Atlantosaurus beds;" gray to green shales.
Jurassic..........................	Unkpapa..	Fine-grained massive sandstones, pink, white, buff, or purple.
	Sundance..	Green shales and thin bedded sandstones.
Triassic..........................	Spearfish..	Red beds.

In the following table are given the thickness of the three Jurassic formations at localities where typical sections were studied:

Locality.	Sundance formation.	Unkpapa sandstone.	Beulah shales.	Total.
Cascade Springs..................	400	50+	Absent	450
Southeast of Hot Springs...........	220	225	"	445
East of Hot Springs..............	242	160	"	402
Buffalo Gap.....................	230	120	"	350
Fuson creek......................	350	100	"	450
Lame Johnny creek.............	284	80	"	364
French creek.....................	150	100	"	250
Dry creek.........................	60–80	90	"	175±
Spring creek.....................	220	40	100	360
Belle Fourche valley.............	.....	Absent	.....	550
Cambria.........................	280	"	100+	380+
Minnekahta......................	300	"	50	350

SUNDANCE FORMATION

GENERAL CHARACTERISTICS

This member of the Jurassic extends continuously around the Black Hills uplift, and throughout its course presents characteristics by which it can be easily recognized. It carries abundant marine fossils, not only to the north, as stated by Newton, but in profusion also around the zone of outcrops to the south. The formation comprises shales and sandstones, in greater part in alternating series which vary somewhat in relation in different portions of the region. The shales are mainly dark green and the sandstones pale buff in color, but there is an intermediate member of sandy shales and sandstones of reddish color, and often a local basal member of red sandstone. The shales usually include thin layers of limestone which are always highly fossiliferous.

Fossils also occur in the sandstone. The remains are molluscan, with the exception of *Pentacrinoides aristicus*, and bone fragments.

FOSSILS OF THE FORMATION

The following is the list of the fossils so far reported:

Ammonites cordiformis
Ammonites henryi
Astarte fragilis
Astarte inornata
Asterias dubium
Avicula mucronata
Belemnites densus
Camptonectes bellistriatus
Camptonectes extenuatus
Dosinia jurassica
Gervillia recta
Grammatodon inornatus
Lingula brevirostris
Lioplacodus veturnus
Myacites nebrascensis
Mytilus whitei
Neæra longirostris
Ostrea engelmanni
Ostrea strigilecula
Pecten newberryi
Pentacrinus asteriscus
Pholodomya humilis
Planorbis veturnus
Pleuromya newtoni
Protocardium shumardi
Psammobia prematura
Pseudomonotis curta
Pseudomonotis orbiculata
Rhynchonella gnathophora
Rhynchonella myrina
Saxicava jurassica
Tancredia æquilateralis
Tancredia bulbosa
Tancredia corbuliformis
Tancredia inornata
Tancredia postica
Tancredia warrenana
Thracia arcuata
Thracia sublevis
Trapezium bellefourchensis
Trapezium subequalis
Trigonia conradi
Unio nucalis
Valvata scarbrida
Viviparus gilli
Volsella pertenuis

GEOLOGICAL SUCCESSION AT VARIOUS LOCALITIES

Vicinity of Catholicon Springs hotel, Hot Springs.—The stratigraphic variations of the formation were traced with care, but the vertical distribution of the fossils has not as yet been determined. Certain members of the formation are of general occurrence, andthere are others which are less persistent. The succession of the lower dark shales, a slabby, buff, ripple-marked sandstone next above, a reddish, sandy shale, and an upper green shale with fossiliferous limestone layers, is continuous over a wide area. At the base of the formation there is often a massive sandstone of red or buff color occurring in extended lenses and often attaining a thickness of 25 feet. Next above are the shales just mentioned, and it is in the sandy layers at the base of these shales, near Hot Springs, that I discovered the fossil fish described by Doctor Eastman in his paper which follows mine. The locality is about one mile east-southeast from the Union railroad station, or one-half mile south of the

Catholicon Springs hotel. It is in a small draw which heads in the sandstone ridge lying east of the Red Bed valley. The succession here is as follows:

Unkpapa sandstone.	
Green shales with belemnites, etc.	80 feet thick.
Red sandy shales	80 " "
Greenish shales and thin sandstones	8 " "
Buff, slabby, ripple-marked sandstone	15 " "
Limestone filled with ostreas	10 " "
Green shales, very sandy	21 " "
Soft, thin-bedded sandstone, fish-bearing layer	4 " "
Buff sand	2 " "
Red beds.	

The buff sand lies on a slightly eroded surface of the Red beds. To the north and to the south it thickens and becomes a conspicuous bed of red to buff sandstone. The limestone with Ostrea is a local lense not found elsewhere. The fish appear to occur only on the surface of one of the sandstone layers about ten inches above the top of the buff sand. Although extensive excavations were made, only a small lot of material was found. A fairly extended scanning of the same horizon in the vicinity revealed only an occasional fish scale.

Hot Springs vicinity.—Near Hot Springs there is considerable stratigraphic variation in the Sundance formation. The general average section is as follows:

Unkpapa sandstone.	
Green shales, belemnites	90 feet thick.
Red sandy shales and sandstones	80 " "
Green shales	8 " "
Buff slabby sandstones, ripple-marked	30 " "
Dark shales	9 " "
Red massive sandstone	25 " "
Red beds.	

The fossils are very abundant, both in the calcareous layers in the upper green shales and in the buff, ripple-marked sandstones. They occur in some of the other beds, but in much less number.

Buffalo Gap vicinity.—At Buffalo gap, where there are extensive exposures, the following beds are seen:

Unkpapa sandstone.	
Green shales with thin fossiliferous limestone beds	100 feet thick.
Red, sandy shales and soft sandstones	65 " "
Greenish buff, sandy shales and thin sandstones	15 " "

Buff slabby sandstones, ripple-marked	40	feet thick.
Pale red, massive, soft, cross-bedded sandstones	7	" "
Purple and buff sandy clays on hard, gray sandstone	4	" "
Red beds.		

Fuson Creek locality.—In the vicinity of Fuson creek the exposures are not sufficiently complete to afford a complete cross-section. The beds outcropping are 8 feet of buff sandstone lying on the Red beds and overlain by 15 feet of dark gray shales with thin, interbedded sandstones, which are succeeded by 20 feet of buff, slabby, ripple-marked sandstone. Some distance higher on the slope there are exposed dark green shales with abundant belemnites and other fossils in calcareous layers. The entire thickness to the base of the Unkpapa sandstone appears to be about 350 feet.

Lame Johnny Creek locality.—In the vicinity of Lame Johnny creek the following section is exposed:

Unkpapa sandstone.		
Buff sandstone, thin bedded below	15	feet thick.
Dark shales with belemnites and other fossils	90	" "
Buff sandstones	35	" "
Red sandstones and sandy shales	80	" "
Buff slabby sandstones, ripple-marked	26+	" "
Black shales	8	" "
Buff sandstones	15	" "
Dark shales	5	" "
Red and buff massive sandstone	10	" "
Red beds.		

Region south of French creek.—In the first canyon south of French creek, nearly due west of Fairburn, the formation is seen to be much thinner than it is elsewhere in the region, and to consist of very arenaceous materials. In the fine section on French creek, a mile north, the formation presents more of its usual composition, as shown in the following section:

Unkpapa sandstone.		
Red and buff soft sandstone	20	feet thick.
Shales with few thin fossiliferous sandstone layers	80	" "
Buff, soft sandstones and shales	20	" "
Massive, buff to red sandstone	30	" "
Red beds.		

Dry Creek canyon.—In the canyon near the head of Dry creek, northwest of Fairburn, the Sundance formation is represented by only 60 or

NATURAL BRIDGE IN FIRST CANYON SOUTH OF BUFFALO GAP

Indicating massive structure of Unkpapa sandstone

80 feet of beds comprising green shales above and thin-bedded sandstones below, the former containing abundant fossils.

Squaw Creek locality.—On Squaw creek, southwest of Hermosa, the formation comprises a thin sandstone at the base, then a mass of shales of dark color, and a top member of buff and yellow slabby sandstone.

Spring Creek locality.—On Spring creek the following features are exposed:

Unkpapa sandstone.			
Buff sandstone, massive above, slabby below	25	feet	thick.
Green shales with three fossiliferous layers and some thin sandstones	75	"	"
Pale greenish, soft, massive, argillaceous sandstone	25	"	"
Pinkish, massive, soft sandstone	6	"	"
Talus	50	"	"
Buff slabby sandstone, ripple-marked	12	"	"
Talus	20	"	"
Greenish shale	5	"	"
Buff sandstone	3	"	"
Red beds.			

The sandstone at the top of this section is a very conspicuous member for some miles on either side of Spring creek, and it appears to have developed out of the sandy beds which usually overlie the upper green shales southward. It is possible, however, that it is a representative of the lower portion of the Unkpapa sandstone which is thin in this vicinity.

Rapid Creek area.—Three miles southwest of Rapid the upper buff sandstone above referred to has a thickness of 25 feet, and it is underlain by a thick mass of green shales containing belemnites and other fossils.

In the vicinity of the gap on Rapid creek west of Rapid and for some miles north the exposures of the Sundance beds are not continuous so as to give a satisfactory section. Shales of buff, gray, and green color, with intercalated beds of sandstones and fossiliferous limestones, are the principal features.

Locality at Cascade.—Returning to the region south of Hot Springs, there is found at Cascade a fairly complete section of the Sundance beds having a thickness of 400 feet. They comprise from the top a succession of green shales with fossil-bearing layers, a considerable thickness of red sandy shales, the usual heavy bed of buff, slabby, ripple-marked sandstone, 60 feet of green shales, and a basal, red, massive sandstone lying on the Red beds.

Southern margin of uplift.—Along the southern margin of the uplift there are extensive exposures of the Jurassic beds which present interesting features. The following section made near Minnehahta Station is typical for a wide area:

Beulah shales.	
Grayish green shales with thin fossiliferous limestone layers	105 feet thick.
Red sandstone with some red and green shales	75 “ “
Pale greenish buff sandstones, thin bedded	10 “ “
Pale grayish green shales	10 “ “
Buff, flaggy sandstones, ripple-marked	35 “ “
Gray shales	40 “ “
Red sandstone, coarse, massive, fossiliferous	25 “ “
Red beds.	

The basal red sandstone is a conspicuous member for several miles west, but towards Pass creek it finally thins out and disappears. Its aspect near Red canyon is shown in plate 42, which shows also the contact with the Red beds.

Vicinity of Newcastle and Cambria.—Along the western slope of the Black Hills near Cambria the formation presents the following average section:

Beulah shales.	
Green shales with fossiliferous calcareous layers	120 feet thick.
Red sandy shales	50 “ “
Thin sandstone and shales	25 “ “
Light buff, slabby sandstone, ripple-marked	25 “ “
Greenis hgray shales	60 “ “
Red beds.	

These features continue far to the north, with some variation in thickness and minor changes in local included beds. The deposit as a whole becomes somewhat more arenaceous and thickens.

Section in Belle Fourche valley.—The following section in the Belle Fourche valley is by Newton. It includes at the top a considerable thickness of the Beulah shales.

Clay or marls, yellowish green and gray, sometimes sandy, with streaks of purple near top	140 feet thick.
Sandstone, brown, lamellar	3 “ “
Clay or marl, brownish and sandy	15 “ “
Limestone, thin stratum, very fossiliferous	
Clay or marl, yellow with red sandy clay at base, exposure not complete	235 “ “

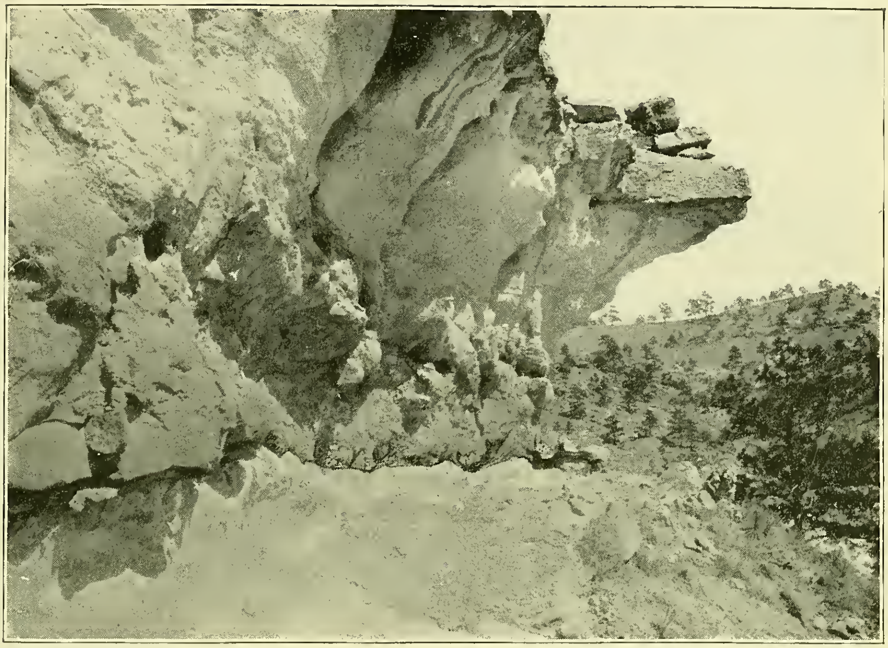

Figure 1.—Lakota Sandstone lying unconformably on Unkpapa Sandstone, north side Sheps Canyon Black Hills

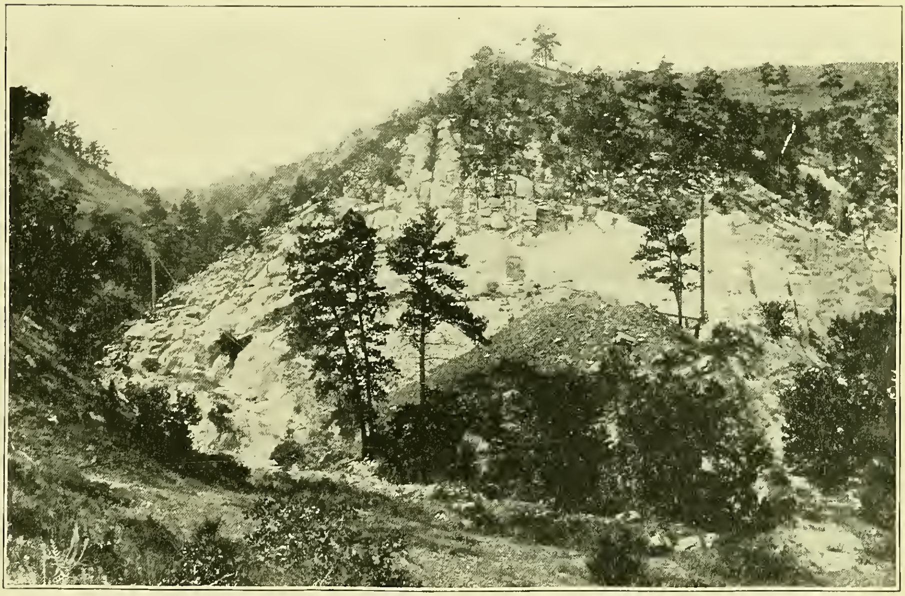

Figure 2.—Unkpapa Sandstone, near Head of Odell Canyon, Black Hills

LAKOTA SANDSTONE AND UNKPAPA SANDSTONE

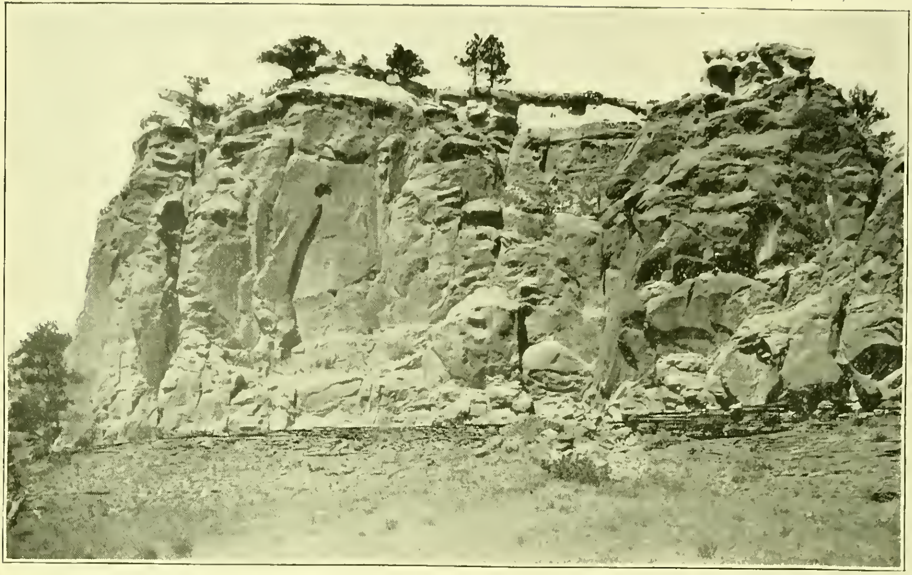

FIGURE 1.—JURASSIC SANDSTONE ON RED BEDS, SIX MILES WEST OF MINNEKAHTA STATION, SOUTH DAKOTA

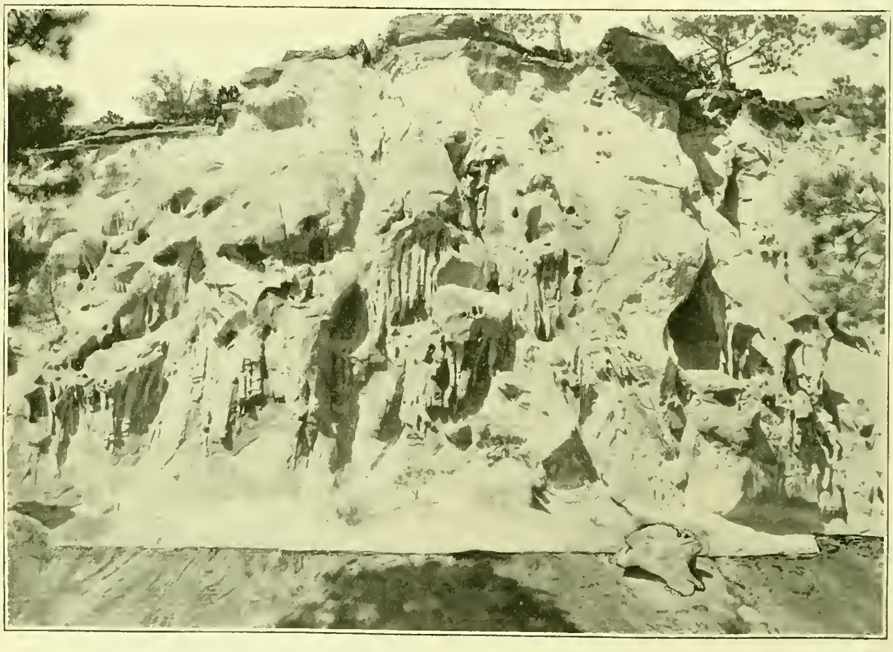

FIGURE 2.—WIND-CARVED JURASSIC SANDSTONE ON RED BEDS, SEVEN MILES SOUTH OF HOT SPRINGS, SOUTH DAKOTA

JURASSIC SANDSTONE ON RED BEDS

Sandstone yellow, in place quite red, shaly at the top, lower part massive........................	50 to 75 feet thick.
Gray or marl gray and greenish with pink streak near the middle, calcareous at base, with flint; includes an impure limestone with many fossils.	120 " "
Red beds.	

UNKPAPA SANDSTONE

This formation is always clearly separable both from the Sundance shales below and the Beulah shales, or Lakota sandstone, above. It is a massive, fine-grained sandstone, varying in color from white to purple and buff. Its greatest development is in the foothill ridges or "hog-backs" east of Hot Springs. Its first outcrops southward are observed at Cascade Springs, and it extends continuously from that region past Hot Springs all along the eastern side of the Hills, with its thickness diminishing north of Buffalo gap. Some of its exposures east of Hot Springs are very striking in their brilliant coloring of pink, purple, and pure white. The thickness is greatest in Shep's canyon southeast of Hot Springs, where 225 feet were measured. In three of the canyons between Fall river and Buffalo gap it has been quarried to some extent for building stone. One of these quarries is shown in figure 2, plate 43. Portions of the rock are banded with various colors in the most beautiful manner, in part along the stratification planes, but often diagonal to them. In the quarry west of Buffalo gap these banded beds exhibit minute faulting, affording fine illustrations of block fault phenomena. The sandstone is characterized in general by its fine grain and very massive but uniform texture. Contacts with the overlying buff sandstone of the Lakota formation are frequently exposed, and they are seen to be marked by considerable unconformity by erosion (see plates 43 and 44).

BEULAH SHALES

This Jurassic member has been designated the Atlantosaurus beds by Marsh and others, but recently Mr W. P. Jenney,* in describing some of the overlying formations in the northern Hills, has named it the Beulah shales. It is a member that has yielded the remains of a number of large saurians collected by Professor Marsh on the north side of Piedmont butte. This formation was regarded by Marsh as unquestionably Jurassic in age, a view which has been generally accepted. The Beulah shales first make their appearance northwest of Hermosa,

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*19th Annual Report of the U. S. Geological Survey, part II, p. 593.

lying between the Unkpapa sandstone and the Lakota formation. They thicken rapidly in their extension northward and pass around the northern and western side of the Hills as a prominent member of the series.

Beyond the edge of the Unkpapa sandstone they lie conformably on the Sundance formation, and owing to the similarity of materials might not be readily separated if their true relations had not been determined on the east side of the Hills. They extend along the western side of the uplift and finally thin out north of Edgemont. The material of the formation is mainly a dark-colored shale, much more fissile, and darker to the east than to the north and west. From Sundance to Cambria and Minnekahta they are a light greenish-gray, somewhat massive mixture of gray clay and sand. They are moderately consolidated and crumble more or less on weathering. In this area some of the beds exhibit purple tints. A few thin sandstone beds are included throughout.

History of the Jurassic Deposits

The geologic history of the Jurassic deposits in the Black Hills region can be outlined in a general way. They represent conditions of deposition intermediate between those under which the Red beds were laid down and those which gave rise to the Lakota and Dakota sandstones. The Black Hills have been a nucleus of uplift and subsidence for a long period, but the sequence of events appears to have been about the same as in the Rocky Mountain region in general. At the end of the period in which the Red beds were deposited, there was an uplift of the entire Black Hills area, with slight erosion, mainly by planation of the red deposits. Then followed submergence, with sandy shores on which accumulated the materials of the massive red sandstones that are now exposed as the basal Jurassic beds in a portion of the region. As this submergence continued argillaceous deposition became almost general, and the materials of the lower shale series were laid down. Early in this stage there were deposited the thinly bedded sandstones containing the fish described by Doctor Eastman.

The next stage was an arrest in the submergence and more vigorous conditions of erosion and deposition, giving rise to the beds now represented by the widely extended series of buff, slabby sandstones usually prominently ripple-marked. In the next stage the conditions were much more diverse in different portions of the region, affording deposits now represented by alternating shales and sandstones with included red beds in most areas. Next came much deeper waters and extensive clay deposition. At this time organic life was particularly abundant, and thin layers of calcareous deposits were developed. Following this came sandy deposition, culminating in the accumulation of beds now represented by the Unkpapa sandstone, which, as above described, has in places a thickness of 225 feet. Apparently the area of deposition at this time was to the east and southeast, for there is no evidence of degradation of the Unkpapa beds where the formation thins out to the west.

The Unkpapa sands were deposited in relatively quiet water, for the material is uniformly fine-grained and rarely shows any current-bedding. Next came the deeper waters in which were deposited a widespread mantle of clay, now represented by the Beulah shales. Although these shales are absent in the southeastern portion of the Hills, yet it is probable that they were originally deposited there to a greater or less thickness and then removed by erosion. This erosion resulted from the uplift which constituted the next stage. How extensive the degradation was is not known, but it has given rise to a general erosional unconformity at the base of the Lakota sandstone, the next succeeding deposit.

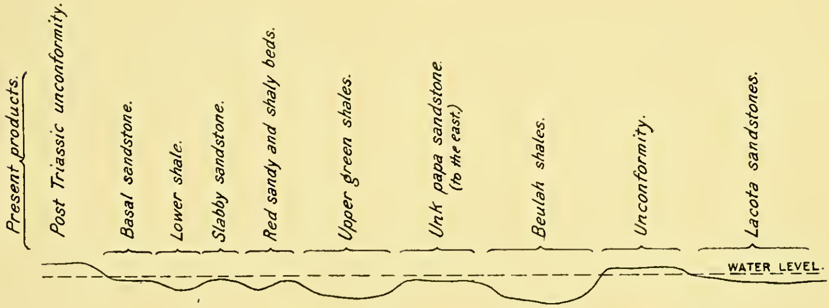

FIGURE 2.—*Outline of History of Jurassic Deposition in Black Hills Region.*

In figure 2 an attempt has been made to represent the principal stages in the cycle of events above described. The diagram has little or no quantitative status, but it shows the nature and general sequence of events.

As the post-Jurassic age of the Lakota formation is not yet definitely ascertained, a few remarks concerning the character and history of this series may be in order here. The materials are mainly coarse, cross-bedded sandstones in thick masses, with intercalated shales, fine clays, and local coal beds. They represent a time in which the waters were shallow and strong currents prevailed over a broad area of the West. These currents carried and deposited a series of widespread sheets of coarse sands, with occasional intercalations of pebbly admixture. There were at this period a number of intervals of deeper or quieter waters with clay deposition and local uplifts, giving rise to shallow surface basins in which carbonaceous deposits were laid down.

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JURASSIC FISHES FROM BLACK HILLS OF SOUTH DAKOTA*

BY C. R. EASTMAN

(*Accepted for publication by the Society May, 1899*)

CONTENTS

SCARCITY OF FOSSIL FISHES IN AMERICAN JURA-TRIAS AND JURA

As contrasted with other countries, the American Jura-Trias contains an extraordinarily meager representation of fossil fishes. The supposed Triassic sandstones of the eastern United States yield in all but six genera and a limited number of species, the majority of which are imperfectly preserved. In none of these has the osteology of the head been satisfactorily worked out, and our knowledge of skeletal details still leaves much to be desired. The existence of piscine life in the western Trias is indicated by sparsely scattered fragments, nothing more.

An even greater dearth of this class of vertebrates prevails in the American Jura, standing in marked contrast to its wealth of reptilian and mammalian remains. A few small Dipnoan teeth, described as *Cera-*

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*This paper was not presented before the Society either by reading or by title, but was accepted by the Publication Committee as a desirable and important adjunct to Mr Darton's paper, which precedes it.

todus guentheri Marsh[*] and *C. robustus* Knight,[†] are the only recognizable forms which have been discovered up to the present time. These species are from the Upper Jura of Wyoming and Colorado, but aside from their evidence as to the widespread distribution of the genus are without special significance.

In view of these circumstances, very great interest attaches itself to the discovery by Mr N. H. Darton, in strata determined by him to be basal Jurassic, of several complete fishes which admit of detailed comparison with other forms, and furnish corroborative evidence as to the age of the horizon. Mr Darton first announced his discovery at the winter meeting of the Geological Society of America in New York last December, and contributed at the same time a brief account of the stratigraphy of the region. About a dozen specimens were exhibited, all from a locality three-quarters of a mile southeast of Hot Springs, South Dakota. Later the material was generously placed in the hands of the writer for investigation, and although a brief summary of the results was read before the Boston Society of Natural History in March of this year, the details were withheld in order that they might appear in conjunction with Mr Darton's published account of the geology of the Black Hills district. Another reason for the delay was the hope of more perfect material being discovered during field work of the present summer; unfortunately, however, this anticipation was not realized.

The only other descriptions of fossil fishes from the Black Hills region are those contributed by Cope[‡] in 1891, the horizon being doubtfully interpreted on the evidence of the fishes themselves as Oligocene. These, naturally, are foreign to the present subject.

DESCRIPTION OF THE MORE PERFECT FOSSILS

Pholidophorus americanus E. (plates 45–47)

> "Gracefully fusiform, upwards of 15 centimeters long, the head forming about one-fourth the total length and slightly less than maximum depth of trunk, dorsal arising behind pelvic fins; scales not serrated, smooth, nearly rhomboidal, overlapping; flank-scales not especially deepened, several series of ventral scales finely divided."

The specific characters were summarized as above in a paper read before the Boston Society of Natural History, an abstract of which appeared in *Science*[§] for May 5, 1899. The association with *Pholidophorus*

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[*] Amer. Jour. Sci. [3], vol. xv, 1878, p. 76, wood cut.

[†] *Ibid.* [4], vol. v, 1898, p. 186, figs. 1 and 2.

[‡] Amer. Naturalist, vol. xxv, 1891, pp. 654–658; Proc. Amer. Assoc. Adv. Sci., vol. xl, 1891, p. 265.

[§] Vol. ix, 1899, p. 642.

was regarded as more or less provisional at the time, for the reason that the cranial osteology, as far as it had then been worked out, showed anomalous features. It was observed that while the dentition, outline of head, and majority of body characters indicated a position with the *Pholidophoridæ*, the arrangement of facial bones was suggestive of *Eugnathidæ*. Inasmuch, however, as the sutures between the thin cheek-plates were extremely difficult to determine and their homologies therefore more or less uncertain, it seemed wisest to rely upon body characters for deciding the generic affinities.

Comparison of Family Characters

The problem which then arose has not yet been solved by the acquisition of more perfect material; Mr Darton, in fact, fears that the fish-bearing stratum at the original locality is exhausted, and he has not been successful in discovering fresh outcrops. A word or two may be offered to explain the exact nature of the difficulty. Such forms as *Eugnathus*, *Heterolepidotus*, *Caturus*, and the like are characterized by the possession of two very large postorbitals in advance of a narrow preoperculum, a ring of small circumorbitals, and at least one large preorbital plate. All these bones are moderately robust and externally enameled; in most cases they are also more or less ornamented. In the *Pholidophoridæ*. on the other hand, the external bones are very delicate, the postorbitals of relatively small size, and together with the circumorbitals completely cover the cheek. The preoperculum is a large and mesially broad triangular plate; both the inter- and suboperculum are relatively larger than in *Eugnathidæ*, the latter plate being separated from the operculum by an oblique suture. Other differences between the two families are set forth in the following table, the characters being compiled from A. S. Woodward's diagnoses: *

Eugnathus, Heterolepidotus, etcetera	*Pholidophorus*
Cranial and facial bones moderately robust, usually ornamented with tuberculations or rugæ; two very large post- (or sub-) orbitals in advance of a narrow, elongate preoperculum; interoperculum small.	External bones delicate, smooth or very feebly ornamented, preoperculum triangular, broad mesially; interoperculum and suboperculum large, the latter divided from the trapezoidal operculum by an oblique suture.
Mandible complex, consisting of dentary, splenial, coronoid, and angular elements; teeth large, in more than one series; a large gular plate present.	Mandible simple, consisting of but two elements (coronoid and splenial not observed); teeth minute and conical; no gular plates.

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* Catalogue Fossil Fishes British Museum, part iii, 1895.

Scales thick, rhombic, slightly overlapping, rugose or crenulated on posterior half of each scale on part of the body; principal flank scales rarely, and then only in part, deeper than broad, several series of ventral scales much broader than deep; no enlarged scales on dorsal ridge nor in vicinity of anus.	Scales thin, rhombic, deeply overlapping, smooth or feebly ornamented; principal flank scales deeper than broad, ventral scales in part broader than deep; a large scale at the base of one or both lobes of the caudal, and three slightly enlarged scales around the anus at base of anal fin.
Lateral line inconspicuous; paired fins with well developed baseosts. Fin-fulcra conspicuous, biserial.	Lateral line opening by widely separated large pores. Paired fins without baseosts. Fin-fulcra delicate.

Scrutinizing the characters of Mr Darton's specimens in comparison with the above table, the preponderance of evidence is seen to favor their association with Pholidophori. Regarding the chief inharmonious feature, arrangement of facial plates, the present material is inconclusive; more perfect forms may compel the erection of a new genus with head parts resembling *Eugnathus*, and partaking of the body characters of *Pholidophorus*. It will be convenient for the present, however, to maintain the provisional reference to the latter genus.

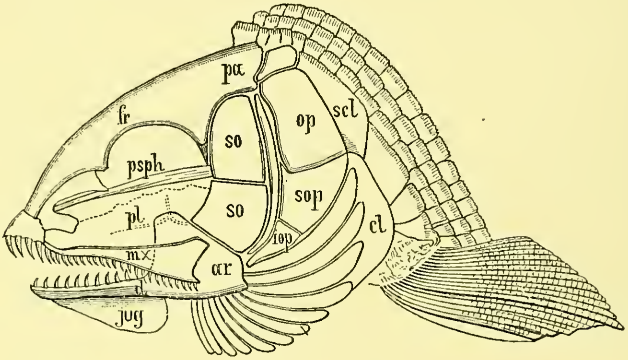

FIGURE 1.—*Head of the so-called Isopholis* (*Ophiopsis*) *muensteri* Wagner.

Showing arrangement of facial bones characteristic of Eugnathidæ: *ar*, articular; *d*, dentary; *jug*, gular plate (displaced downward); *pl*, palatine; other letters as in figure 2. Specimen is from lithographic slates (Upper Jura) of Kelheim, Bavaria (after Zittel).

This species is not the only one to occupy an anomalous position for kindred reasons. Certain species of *Pholidophorus* and *Ophiopsis* are united by Zittel* under the new generic title of *Isopholis*. The head figured by him as *I. muensteri*, a reproduction of which is given herewith in figure 1, can not be distinguished from *Eugnathus*, but the vertebral centra are stated to be well ossified, a condition which is unknown among Eugnathidæ or Pholidophoridæ. Agassiz's *Pholidophorus longiserratus*

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* Handbook of Palæontology, vol. iii, 1887, p. 216, figure 230.

and Wagner's *P. brevivelis* are transferred to *Isopholis* by Zittel, and to *Eugnathus* by Woodward.* *P. crenulatus* of Egerton is retained by the last-named authority among the Pholidophoridæ but by Zittel is ranged alongside of *I. muensteri.*

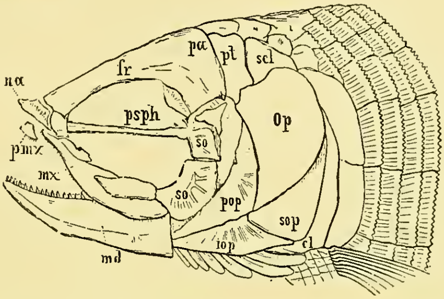

Figure 2.—*Head of Pholidophorus macrocephalus* Ag.

From lithographic slates of Eichstädt, Bavaria. *cl*, clavicle; *fr*, frontal; *iop*, interoperculum; *md*, mandible; *mx*, maxilla; *na*, nasal; *op*, operculum; *pa*, parietal; *pmx*, premaxilla; *pop*, preoperculum; *psph*, parasphenoid; *pt*, supratemporal; *scl*, "supraclavicle" (? post-temporal); *so*, suborbital; *sop*, suboperculum (after Zittel).

These instances merely emphasize the difficulties of effecting a trenchant separation among similar or annectant types. Figures 1 and 2 will serve to illustrate the different patterns of cranial structure in *Eugnathus* and *Pholidophorus* respectively, and also as a key for distinguishing the corresponding parts in plates 45–47.

Method of preparing Illustrations used

Before passing to a detailed description of parts, a word should be said explanatory of the illustrations.

Plate 45 is reproduced from photographic negatives without retouching of any kind. The three figures show the specimens just as they were found, and are very nearly of the natural size. Figure 2 shows the right side of a fish preserved in counterpart, the opposite half yielding a very sharp reverse impression, and employed as a groundwork for plate 46, figure 2. The originals of plate 46, and of plate 47, figures 2, 3, and plate 48, figure 3, are all in the form of counterpart impressions. They were first photographed, and the positives printed very light on platinum paper. The details were then carefully worked out in India ink with the point of a brush by the well known artist, Mr J. Henry Blake, of Cambridge. Figures 1, 4, and 5 of plate 47 (the last two being counterparts of the same specimen) and figure 1 of plate 48 are reproduced directly from photographs without retouching. Figure 2 of plate 48 is from an en-

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* Loc. cit., p. 301.

larged drawing of a detached scale. In no case has anything been added to the drawings which was not clearly indicated on either the original fossil or its counterpart, and the only chance for inaccuracy lies in the delineation of facial sutures in plate 46. It is almost impossible in some cases to distinguish the latter from accidental fractures. To a limited extent, therefore, this plate stands in the nature of a restoration.

Details of Body Parts

HEAD

The cranial and facial bones are smooth and delicate, those of the cranial roof forming a continuous shield, as shown in plate 46, figure 1. The parietals can not be recognized on any of the specimens as separate elements, and the median suture of the frontals is straight, making the latter a symmetrical pair. The snout is not produced, and the small premaxillæ are not only mesially in contact, but appear to be fused (plate 47, figure 2 above the mandible). The maxillæ are stout (plate 47, figure 3) and their convex oral margin provided with a row of minute teeth; the vomer and supramaxillæ have not been recognized as such. The mandible is simple, rounded and expanded in its articulo-angular portion (plate 46 and plate 47, figure 2). The orbits are large, with a peculiar discoloration of the matrix in the center, possibly due to chemical change of salts contained within the eye itself. Surrounding the orbits is a ring of small, regularly disposed circumorbitals (plate 46, figure 1), behind which are two moderate-sized but very thin postorbitals (suborbitals), situated one above the other, the lowermost being somewhat the larger.

A narrow space intervenes behind the postorbitals, separating them from the operculum and suboperculum, and extending downward and forward as far as the mandible (plate 46, especially figure 1). This space corresponds in position to the preoperculum and is remarkable for its narrowness. The operculum considerably exceeds the suboperculum in size, is irregularly elliptical in shape, apparently convex in some specimens (plate 46 and plate 47, figure 3), and in one at least is marked by faint radiating rugæ (plate 46, figure 1). The suboperculum is a triangular piece with rounded outlines, and encroaches over all the space normally occupied by the interoperculum. None of the specimens show the latter plate as a separate element, and to all appearances the series of branchiostegal rays follows immediately beneath the sub- and preoperculum. There are about 14 laminar branchiostegal rays in the series shown in plate 47, figure 2, and a lesser number are visible in plate 46, figure 1.

Behind the opercular apparatus occurs a long and rather large arched clavicle, traversed by longitudinal striæ. Adjoining it are to be seen on one or two specimens impressions of postclavicular scales, which are likewise striated. The supraclavicle is not distinguishable.

FINS

The dorsal and anal fins are triangular in shape, not extended, and of about medium size, the dorsal arising slightly behind the pelvic fins, which are abdominal in position. The pectorals are much larger than the pelvic fins, and both are without basal supports. Were baseosts present, they could hardly fail to be preserved on such specimens like those shown in plate 46, figure 1, and plate 47, figures 1–3; their absence is an important distinguishing characteristic. Another minor point of difference from *Eugnathus* is seen in the regular scale arrangement at the base of the deeply forked caudal fin.

Well developed fulcra are present along the anterior margin of the dorsal, anal, and paired fins, and on both lobes of the caudal. The rays of the latter are very finely divided and the right and left halves liable to displacement, which makes them difficult to count. For this reason a precise radial formula cannot be given, and the following must be considered as merely approximate:

D 10; C 25–28; A 12; V 9; P 15.

SCALES

The trunk is covered with thin, smooth ganoid scales of rhombic outline, arranged in 45 regular oblique series, four or five of which occur on the tail, and in about 22 longitudinal series counting along the middle of the body. The principal flank scales are somewhat deepened for a variable distance behind the head, but their depth rarely exceeds twice their breadth. Several series of ventral scales are much broader than deep, and in advance of the anal fin are much subdivided. The principal flank scales are united by a peg-and-socket articulation, but there is no evidence of a vertical rib on the inner face. The overlapped border is rather narrower than in most Pholiphoridæ.

Several large postclavicular scales are connected with the clavicle, and appear to have been covered with delicate longitudinal or branching striæ. A few enlarged scales are to be noticed along the dorsal and ventral margins of the caudal pedicel (plate 47 figure 2), and also close to the anal fin. These last undoubtedly mark the position of the anus (plate 45, figure 1; plate 46, figure 1). Two or three specimens exhibit the lateral line distinctly; it is very well shown on both halves of the specimen photographed in plate 47, figures 4 and 5.

DETAILS OF FIGURED SPECIMENS

The original of plate 45, figure 1, measures 13 centimeters from extremity of mandible to tip of ventral lobe of the tail, and its maximum depth is 3 centimeters. Prominent scale features are the fine subdivision of the ventral series, enlarged anal and striated postclavicular scales, also the peg-and-socket articulation shown in several detached flank scales. The facial plates are fairly distinct, and should be compared with those shown in plate 46, figure 1; also with the wood cuts on pages 400 and 401.

The fish shown in plate 45, figure 2, has a total length of about 11.5 centimeters, and maximum depth of 2.5 centimeters. Its impression in counterpart shows various details more clearly than the actual fossil, and for that reason was employed as a basis for the partly restored drawing shown in plate 46, figure 2. The most perfect example of all, and therefore selected as the type of this species, is represented in plate 46, figure 1. It is preserved in the form of an impression, the opposite half being lost, unfortunately. The total length is about 13 centimeters, and that of the head 2.5 centimeters, which is slightly less than the maximum depth of trunk. This specimen shows the head bones better than all others, but still leaves much to be desired. The cranial roof has been displaced upward, exposing the dorsal surface of the parieto-frontal piece. The raised median line evidently represents the suture between the paired frontals; here it is straight, but in *Eugnathus* it forms a wavy line, and the frontals are unsymmetrical. Indications of a circumorbital ring are also to be seen on this specimen. The position of the anus is marked by two enlarged scales befere the origin of the anal fin; the pelvic is not preserved.

Whether the original of plate 47, figure 1, should be included in the same species with the rest is doubtful, as the roughened, almost papillose condition of the scales seems attributable more to ornament than to corrosion or wear. The anterior flank scales are deeper than in all other specimens, some of them being nearly three times deeper than broad. Branching longitudinal striæ appear on the impressions of postclavicular scales, and the cranial roof has the same roughened aspect as the scales. A median suture is recognizable between the frontals, although not very distinct. The clavicle is well displayed, as is also the base of the pectoral fin. Further material will be necessary to establish or disprove the specific identity. Total length, 16 centimeters; length of head, 4 centimeters.

One of the halves of a small specimen preserved in counterpart is shown in plate 47, figure 2, some of the details being added from the opposite slab. The view here presented is part ventral and part lateral, the posterior part of the body lying on its right side. As the total length is only about 12 centimeters, the pectoral fins and mandibles are seen to be relatively larger than in preceding examples, and the scales at the base of the caudal fin are enormously enlarged. No basal supports for any of the fins are preserved; there is likewise no trace of a gular plate nor of verebral rings. A complete series of laminar branchiostegals is exhibited, in front of which lies a small dentigerous plate supposed to be the fused premaxillæ.

The remaining figures of plate 47 are of small forms preserved in counterpart. Figures 4 and 5 show the right and left halves of the same specimen, and are reproduced from negatives without retouching. They show the lateral line very conspicuously; also the finely branched caudal fin rays and delicate squamation. The fish is probably an immature example of the same species as the foregoing, and is about half the size of the type specimen. Figure 3 of plate 47 is likewise of a small form with delicate squamation. It has a strong, well ossified maxilla and convex opercular plates. The number of transverse and longitudinal scale-series cannot be counted accurately, but appears to be greater than in other examples. It is probable, therefore, that another species is indicated, at present indefinable. None of the specimens exhibit any trace of vertebral centra, ribs, or fin supports.

RELATIONS TO OTHER SPECIES

More than 40 species of *Pholidophorus* have been described from all parts of the world, many of which, however, are founded on imperfectly determinable material. They range from the Upper Trias to the Upper Jura, and with the exception that later forms are often more highly ornamented than the earlier, exhibit remarkably constant characters. On the basis of scale ornamentation two series are recognizable, one having and the other being without serrated scales. The present species finds its place among the smooth-scaled forms, and is not far removed from the type species, *P. bechei* Agassiz, from the Lower Lias. The Eugnathidæ have precisely the same range as Pholidophoridæ, and any inferences as to stratigraphic correlation derived from the one are equally applicable to the other. The paleontologic evidence is entirely in accord with Mr Darton's determination of the horizon as basal Jurassic.

DESCRIPTION OF FRAGMENTARY FOSSILS

*AMIOPSIS (?) DARTONI SP. NOV.**

Plate 48, figures 1, 2.

Associated with the preceding species are numerous fragmentary remains, indicating fishes of large size, with powerful fins and delicate cycloidal scales. Although vertebral centra have not been observed, the presence of stout ribs suggests a well ossified vertebral column. No head bones beyond those shown in plate 48, figure 1, exist in the collection, and the only clue as to systematic position is the decidedly uncertain one afforded by scale characters. These point to a place among the Amiidæ.

The scales are covered superficially with a very thin coating of ganoine, their contour is almost perfectly elliptical, and they appear to have been deeply overlapping. The major axis of the ellipse, which was presumably longitudinal, measures about 1 centimeter in the larger scales. A number of them are to be seen, although rather indistinctly, in the lower part of figure 1, and an enlarged drawing is given of a detached scale in figure 2 of plate 48. In the upper part of figure 1 may be recognized the right and left clavicles and a large semicircular operculum, not unlike that of the recent *Amia*. The large pectoral fin, with curved, distally articulated rays to the right of the operculum, is still attached to a part of the clavicle, broken off from the upper portion. In line with the pectoral below lies the pelvic fin; below and to the left is seen one of the unpaired appendages, possibly the anal fin, overlying which at one end is a rib and at the other the anterior margin of the opposite pectoral. There are no fin-fulcra.

It is greatly to be hoped that further material may be discovered which shall elucidate the structure and relationships of the form here so obscurely represented. There exist as yet only slight grounds for assuming a relationship with *Megalurus*, *Amia*, etcetera, much less for instituting comparisons with them. If correctly referred to the Amiidæ, the present occurrence extends the range of this family at least as far back as the Lower Jura, whereas hitherto it was supposed to have been initiated in the Upper Jura. At all events it is interesting to know now, if we can know no more, that the two groups of rhombic and thin cycloidal

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*The specific title is given in honor of Mr N. H. Darton, who discovered all the remains described in this paper.

scaled ganoids existed side by side in the American Jura as they did in the European. The name *Amiopsis*, first proposed by Kner for an imperfect Cretaceous fish resembling *Amia*, is used here in lieu of a more definite title, and implying that the remains are supposed to be Amioid, but the genus is indeterminable. The specific title is given in honor of Mr N. H. Darton, who discovered all the remains described in this paper.

FIN FRAGMENTS

Plate 48, figure 3. Genera and species not determined.

A very interesting fin structure is that shown one-third larger than natural size in figure 3 of plate 48. Nothing is known of the fish it belonged to, and little can be said of the specimen itself except that it is peculiar in having the anterior margin developed into a strong, spiniform cutwater through coalescence of enlarged fin rays. The latter are not articulated in their proximal portions, and the short, inosculated outer ones apparently not at all. The arrangement of these external rays is curious, and at first sight suggestive of fulcra. They are distinctly fin rays, however, and have nothing to do with the latter structures. The smaller rays adjoining the cutwater are all finely articulated, and are of about uniform size. There can be little question that the appendage here shown is a pectoral fin, with the rays and cutwater preserved in their natural relations. That there has been little or no displacement is shown by the parallelism and proximal origin of all the rays from the cutwater downward to the posterior margin. A smooth coating of ganoine covers all the rays of the cutwater.

Explanation of Plates

Plate 45.—*Pholidophorus americanus* E.

Figures 1, 2.—Full grown individuals seen from the right side, reproduced from photographic negatives without retouching. Both figures very nearly of the natural size.

Figure 3.—Photograph of caudal portion of another adult individual.

Plate 46.—*Pholidophorus americanus* E.

Figures 1, 2.—Enlarged photo-drawings of adult individuals; the details of figure 2 taken in part from opposite half of counterpart. Both figures enlarged about $\frac{5}{3}$ natural size.

Plate 47.—*Pholidophorus americanus* E. (*pars* ?)

Figure 1.—Photograph of large, fragmentary specimen with roughened scales, possibly belonging to a distinct species. Natural size.

Figure 2.—Photo drawing of small individual seen from ventral aspect, showing mandibles, premaxillæ, branchiostegal rays, details of fin structure, etcetera. One-fifth larger than natural size.

Figure 3.—Photo-drawing of small individual with numerous scale-series, convex operculum and strong maxilla, possibly belonging to a distinct species. Natural size.

Figures 4, 5.—Posterior half of young individual preserved in counterpart, showing delicate squamation and conspicuous lateral line.

Plate 48.—*Amiopsis* (*?*) *dartoni* sp. nov. *and an undetermined ganoid.*

Figure 1.—Photograph of naturally associated fragments of large fish with thin cycloidal scales. Clavicles and operculum shown near the top, fin rays (both pectorals, pelvic and anal), ribs, and scales toward the bottom of figure. Five-sixths natural size.

Figure 2.—Detached scale, two-thirds larger than natural size.

Figure 3.—Pectoral fin of undetermined ganoid, proximal end at left-hand side of figure, distal below and to the right. One-third larger than natural size. From photo-drawing by Mr J. H. Blake.

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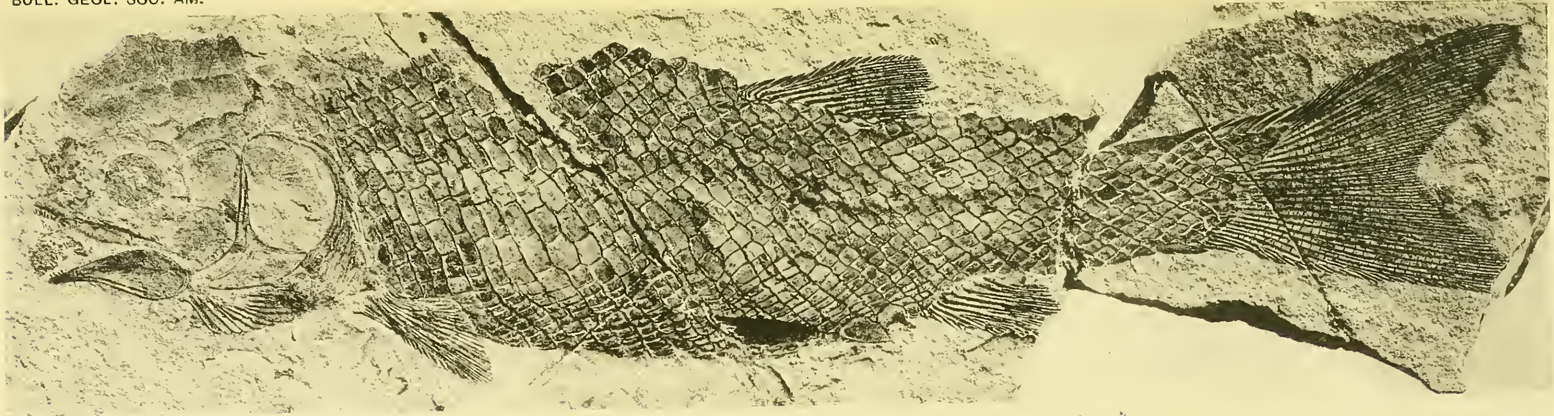
PHOLIDOPHORUS AMERICANUS



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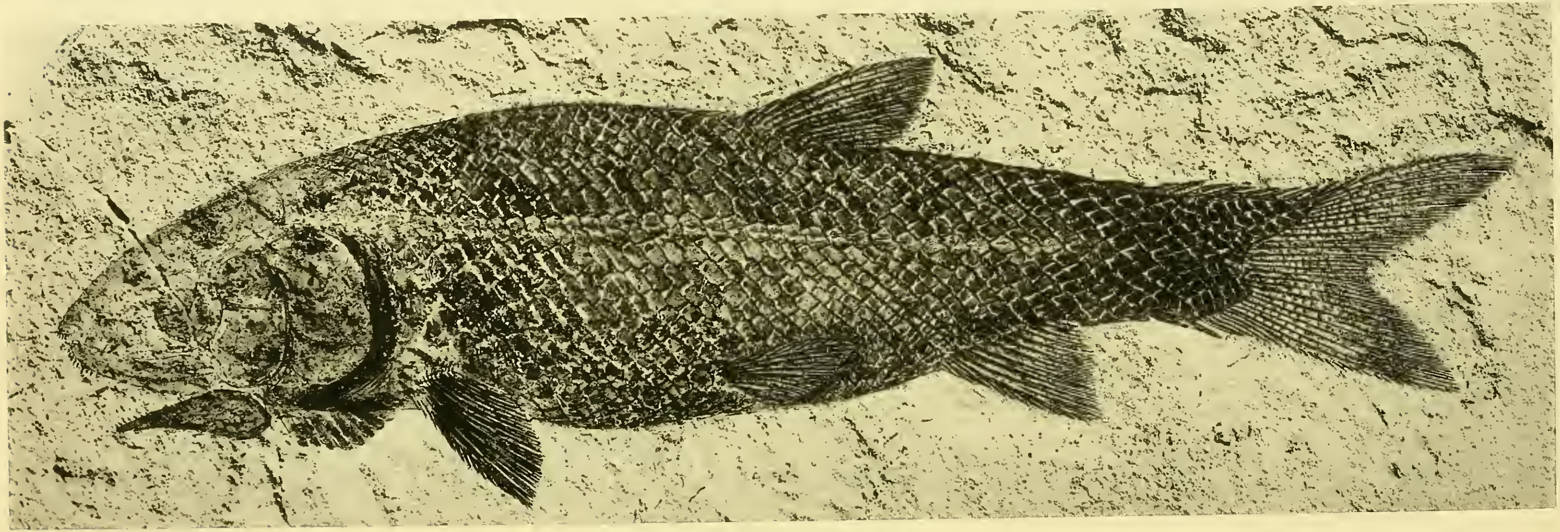

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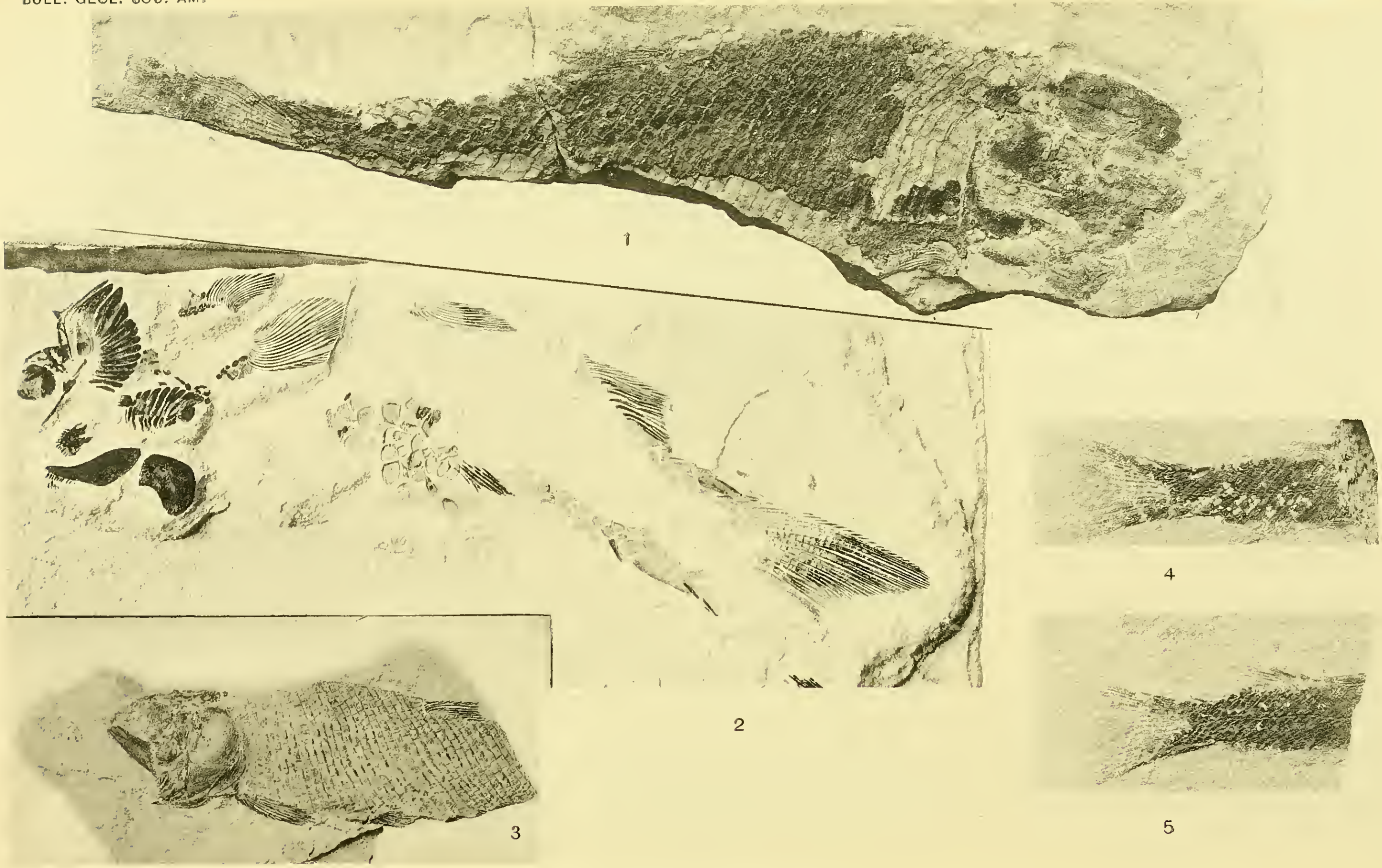
PHOLIDOPHORUS AMERICANUS



PHOLIDOPHORUS AMERICANUS

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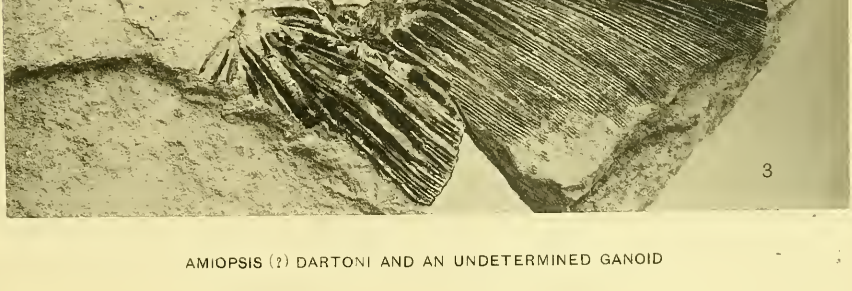

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AMIOPSIS (?) DARTONI AND AN UNDETERMINED GANOID

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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PROCEEDINGS OF THE ELEVENTH ANNUAL MEETING, HELD AT NEW YORK CITY, DECEMBER 28, 29, AND 30, 1898

Herman Le Roy Fairchild, *Secretary*

CONTENTS

Session of Wednesday, December 28

The Society convened in the assembly-room in Schermerhorn hall, Columbia University, at 10.15 o'clock a m. President J. J. Stevenson introduced the Honorable Seth Low, president of Columbia University, who gave the Society welcome in a few remarks expressing appreciation of the science of geology.

The President called for the Council report as the first administrative business, which report was submitted in print by the Secretary without reading, as follows:

REPORT OF THE COUNCIL

To the Geological Society of America,
in Eleventh Annual Meeting assembled:

The Council extends congratulations to the Fellows upon the excellent condition and prospects of the Society at the close of the first decade. Begun with misgivings as to the wisdom of the new organization, and amid prophecies of failure, it has more than justified the faith and work of its founders. The Society has united the geologists of the continent, produced harmony of feeling, thought, and labor, created and cemented friendships, and prevented the geology of America from becoming provincial. It has stimulated research and publication and has placed on record a great body of knowledge. The avowed purpose of the Society—" the promotion of the Science of Geology in North America "—has been carried out.

We may believe that the great success already achieved is but the beginning of a grander future. Already the Bulletin has given us a prominent place among the older geological societies of the world, and with the great advantages possessed by American students of earth-lore it may be expected that at a time not far distant our Society will occupy a foremost position.

We may well be proud of our Society and of our science, which, born so recently, has become a powerful factor in the intellectual uplifting of mankind. Let us sustain and cherish the Society as a noble means to a great end, and may every Fellow realize that he has a useful part, even though he be isolated in a distant field and unable to attend the meetings. To such Fellows the Council sends especial salutation.

During the past year the Council has held only one meeting, at Montreal, no quorum being present at Boston. The necessary business since the annual meeting has been transacted by correspondence.

The following reports of the officers contain all further matters of interest to the Society at large:

SECRETARY'S REPORT.

To the Council of the Geological Society of America:

Meetings.—The record of the Tenth Annual Meeting, held at Montreal December, 1897, is before the Society in print. The proceedings of the Tenth Summer Meeting are in type and will soon be distributed. Like the 1896 Summer Meeting, the Boston meeting occupied one day of the time of Section E, American Association for the Advancement of Science. This arrangement seems mutually satisfactory.

A list of the meetings of the Society held during the ten years is appended, with the number of Fellows and Fellows-elect in attendance, and the number of titles of papers presented (not including reports nor memorials).

	Summer meetings.	Papers.	Attendance.	Winter meetings.	Papers.	Attendance.
1888	....	....	....	1. Ithaca	0	13
1889	1. Toronto	11	53	2. New York	35	60
1890	2. Indianapolis	10	22 (?)	3. Washington	55	66
1891	3. Washington	34	83	4. Columbus	27	23
1892	4. Rochester	15	32	5. Ottawa	37	29
1893	5. Madison	20	38	6. Boston	59	51
1894	6. Brooklyn	29	34	7. Baltimore	48	64
1895	7. Springfield	18	31	8. Philadelphia	26	61
1896	8. Buffalo	14	43	9. Washington	50	79
1897	9. Detroit	12	21	10. Montreal	33	31
1898	10. Boston	18	46	11. New York	—	—

Membership.—Since the last report. 1897, three Fellows have resigned and five have been dropped from the roll for non-payment of dues. Four Fellows elected at Montreal, added to the roll, made the last printed list (July, 1898) contain 238 names. The death of James Hall transfers one name to the list of deceased Fellows, leaving the present membership 237. Two resignations are pending and eight Fellows are delinquent in dues. Eleven persons are now candidates for election at the approaching meeting.

The Society began with 112 "Original" Fellows. The number of Fellows on the roll at the time of the annual meetings during the ten years is as follows: 1888, 98; 1889, 173; 1890, 197; 1891, 213; 1892, 219; 1893, 236; 1894, 226; 1895, 226; 1896, 233; 1897, 242; 1898, 237.

In 1893 the Society had secured the adhesion of nearly all the active geologists of the continent. Since that time the membership has remained quite uniform, the losses being balanced by elections. During the late years of financial stringency many Fellows have been forced unwillingly to relinquish membership. In all, 37 Fellows have been dropped from the rolls for non-payment of dues. Ten Fellows have resigned and 21 Fellows have died. The total number of persons who have been Fellows is 305, of whom two are women.

It is not expected that the membership of the Society will be much larger than at present. Accessions will be mainly from young men entering the profession, which will perhaps only balance the losses.

Following is a tabulation of the geographical distribution of the fellowship in 1888, 1894, and at the present time:

	Original Fellows, 1888.	*Fellows December, 1894.*	*Fellows December, 1898.*
District of Columbia	13	34	37
New York	21	27	29
Canada	..	23	20
Pennsylvania	10	17	15
Massachusetts	7	17	19
California	4	12	10
Ohio	6	12	7
Illinois	1	10	11
Iowa	4	7	8
Connecticut	4	7	6
Minnesota	3	6	5
Michigan	3	5	7
New Jersey	5	5	4
Kentucky	4	4	3
Wisconsin	3	3	6
Missouri	2	4	5
Texas	4	3	3
Alabama	1	3	4
Colorado	..	3	4
Kansas	2	3	2
Virginia	1	3	4
Maryland	2	2	3
Indiana	2	1	4
South Dakota	..	2	2
Vermont	..	2	1
West Virginia	1	2	2
Arizona	..	1	1
Georgia	1	1	1
Idaho	..	1	..

	Original Fellows, 1888.	*Fellows December, 1894.*	*Fellows December, 1898.*
Maine	..	1	1
Mississippi	1	1	..
North Carolina	1	1	2
New Hampshire	1	1	2
Nebraska	2	..	1
Tennessee	1	1	1
Arkansas	1	..	..
Rhode Island	1	1	..
Montana	..	..	1
Wyoming	..	..	1
New Mexico	..	..	1
Utah	..	..	1
Mexico	..	1	2
Brazil	..	1	1
Burma	..	1	..

OFFICERS OF THE SOCIETY, 1889-1898

	President	*First Vice-President*	*Second Vice-President*
1889	James Hall.	James D. Dana.	Alexander Winchell.
1890	James D. Dana.	John S. Newberry.	Alexander Winchell.
1891	Alexander Winchell.	G. K. Gilbert.	T. C. Chamberlin.
1892	G. K. Gilbert.	Sir J. W. Dawson.	T. C. Chamberlin.
1893	Sir J. W. Dawson.	T. C. Chamberlin.	J. J. Stevenson.
1894	T. C. Chamberlin.	N. S. Shaler.	George H. Williams.
1895	N. S. Shaler.	Joseph Le Conte.	C. H. Hitchcock.
1896	Joseph Le Conte.	C. H. Hitchcock.	Edward Orton.
1897	Edward Orton.	J. J. Stevenson.	B. K. Emerson.
1898	J. J. Stevenson.	B. K. Emerson.	G. M. Dawson.

Secretary		*Treasurer*	
J. J. Stevenson	1889-1890	Henry S. Williams	1889-1891
H. L. Fairchild	1891-	I. C. White	1892-

Editor		*Librarian*	
W J McGee	1890-1892	H. P. Cushing	1898-
Joseph Stanley-Brown	1893-		

Councillors

John S. Newberry	1889	E. W. Claypole	1891-1892
J. W. Powell	1889-1890	John C. Branner	1891-1893
Chas. H. Hitchcock	1889-1892	Henry S. Williams	1892-1894
George M. Dawson	1890-1893	N. H. Winchell	1892-1894
I. C. White	1891	E. A. Smith	1893-1895
J. J. Stevenson	1891	C. D. Walcott	1893-1895

Councillors

F. D. Adams	1894–1896	J. S. Diller	1897–1899
I. C. Russell	1894–1896	W. B. Scott	1897–1899
R. W. Ells	1895–1897	W. M. Davis	1898–1900
C. R. Van Hise	1895–1897	Robert Bell	1898–1900
B. K. Emerson	1896–1897	M. E. Wadsworth	1898–1900
J. M. Safford	1896–1898		

Distribution of Bulletin.—The distribution for the year is included in the following table:

DISTRIBUTION OF BULLETIN FROM THE SECRETARY'S OFFICE DURING THE YEARS 1891–1898

Complete Volumes

	Vol. 1.	Vol. 2.	Vol. 3.	Vol. 4.	Vol. 5.	Vol. 6.	Vol. 7.	Vol. 8.	Vol. 9.
Distributed to Fellows	..	..	209	214	214	223	222	231	234
Donated to "exchanges"	91	91	89	89	89	87	85	85	84
Sold to libraries	89	89	91	87	83	89	82	79	77
Sold to Fellows	24	18	12	8	5	3	2	....	....
Sent to Fellows, deficient	2	1	1	....	....	....	....	1	....
Donated	4	4	3	3	3	3	2	2	1
Bound for offices and library	3	3	3	3	3	3	3	3	3
Volumes in reserve	51	300	342 (?)	346 (?)	337 (?)	92 (?)	104 (?)	99 (?)	101 (?)
Complete vols. received	264	506	750 (?)	750 (?)	734	500 (?)	500 (?)	500 (?)	500 (?)

Brochures

	Vol. 1.	Vol. 2.	Vol. 3.	Vol. 4.	Vol. 5.	Vol. 6.	Vol. 7.	Vol. 8.	Vol. 9.
Sent to Fellows, deficient	50	141	46	43	28	13	15	12	5
Sent to libraries, deficient	3	7	5	6	3	1	4	8	2
Sold to Fellows	19	22	11	13	19	8	2	3	....
Sold to public	13	15	17	13	7	11	6	6	1
Donated	3	3	3	3	2	....	....	....	....

Subscriptions.—The list of subscribers to the Bulletin remains the same as last year, one new subscriber, the John Crerar Library, Chicago, balancing the withdrawal of Cornell College, Mt. Vernon, Iowa. The Secretary has planned to again advertise the Bulletin among educational institutions and libraries, using pages out of volume 9.

Bulletin sales.—Receipts for the past year are $426.65. The reduction from last year is due to delay in the publication of volume 9. In former years the completed volume has been distributed in June or July, which allowed several months for collection of the bills. As the distribution of complete copies of volume 9 has been only within the past week' these sales appear under the item "Charged and uncollected." Moreover, the irregular sales which follow the publication of each volume have not been realized, but will appear in next year's report.

RECEIPTS FROM SALE OF BULLETIN DURING 1898

By Sale of Complete Volumes

	Vol. 1.	Vol. 2.	Vol. 3.	Vol. 4.	Vol. 5.
From Fellows	$18 00	$22 50	$20 00	$17 50	$16 00
From libraries	10 00	10 00	10 00	10 00	15 00
Total for 1898	28 00	32 50	30 00	27 50	31 00
By last report (1897)	534 10	508 50	488 50	452 50	422 00
Total to date	$562 10	$541 00	$518 50	$480 00	$453 00
	Vol. 6.	Vol. 7.	Vol. 8.	Vol. 9.	Total
From Fellows	$8 00	$8 00	$4 00	....	$114 00
From libraries	20 00	20 50	20 00	$125 00	240 50
Total for 1898	28 00	28 50	24 00	125 00	354 50
By last report (1897)	443 00	393 50	370 00	45 00	3,657 10
Total to date	$471 00	$422 00	$394 00	$170 00	$4,011 60

By Sale of Brochures

	Vol. 1.	Vol. 2.	Vol. 3.	Vol. 4.	Vol. 5.
From Fellows	$2 15	$0 50	$22 40	....	$0 60
From public	1 60	....	70	$1 20	....
Total for 1898	3 75	50	23 10	1 20	0 60
By last report (1897)	23 45	20 75	14 65	10 40	6 25
Total to date	$27 20	$21 25	$37 75	$11 60	$6 85
	Vol. 6.	Vol. 7.	Vol. 8.	Vol. 9.	Total.
From Fellows	$0 45	$1 50	$0 25	....	$27 85
From public	20	....	....	$0 60	4 30
Total for 1898	65	1 50	25	60	32 15
By last report (1897)	7 60	6 95	4 30	....	94 35
Total to date	$8 25	$8 45	$4 55	$0 60	$126 50

Grand total	$4,138 10
Received for volume 10 in advance	40 00
Total receipts to date	$4,178 10
Charged and uncollected	231 75
Total sales of Bulletin to date	$4,409 85

Exchanges.—The list of institutions to which the Bulletin is donated is one less than last year, 84 in number, Rassegna delle Scienze Geologische in Italia, Rome, having been reported defunct. This list appears on pages 443–449 of volume 9.

Expenses.—The following table covers the cost of administration for the last fiscal year:

EXPENDITURE OF SECRETARY'S OFFICE FOR THE FISCAL YEAR, NOVEMBER 30, 1897, TO NOVEMBER 30, 1898

Account of Administration

Postage	$16 55	
Expressage	2 75	
Printing (including stationery and records)	70 65	
Meetings (not included in printing)	4 65	
Total		$94 60

Account of Bulletin

Postage	$77 50	
Expressage and freight	35 12	
Wrapping material and labels	2 60	
Printing	2 00	
Collection of checks	2 25	
Total		$119 47
Total expenditure for year		$214 07

Respectfully submitted. H. L. FAIRCHILD,
Secretary.

ROCHESTER, N. Y., *December 20, 1898.*

TREASURER'S REPORT.

To the Council of the Geological Society of America:

The accompanying statement of receipts, disbursements, and investments for the current year (December 1, 1897, to December 1, 1898) exhibits in detail the present very satisfactory financial condition of the Society.

The chief points of interest may be noted as follows:

The names of five (5) Fellows (the same number as last year) have been dropped from the roll for non-payment of dues, each being three years in arrears.

The Fellows delinquent on dues for 1897 and 1898 number only eight (8), compared to fifteen (15) last year. Several of the eight have given notice of withdrawal, so that all but one, or possibly two, will drop out of our ranks early in the coming year, under the operation of section 3, chapter 1, of the By-Laws, since each will, after January 1, 1899, be more than two (2) years in arrears.

Thirty-one (31) Fellows are delinquent on dues for 1898, against thirty-four (34) at the same time last year.

Six (6) life commutations have been received, by payment of one hundred dollars ($100) each, so that the names of E. H. Barbour, J. P. Lesley, Arthur M. Miller, R. A. F. Penrose, J. W. Powell, and J. E. Talmage are now added to the previous list of twenty-nine, thus making thirty-five (35) in all who have secured life membership.

The invested funds of the Society have been increased two thousand dollars ($2,000) during the year, raising the total to five thousand dollars ($5,000), the cost of which to the Society has been $5,120.86.

The annual interest accruing upon these investments is two hundred and seventy-three dollars ($273); or five and one-third ($5\frac{1}{3}$) per centum upon the total cost, a very satisfactory rate considering the high character of the securities purchased.

The Council at its last meeting appointed the President, Treasurer, and Professor Scott a committee upon investments, with instructions to add fifteen hundred dollars ($1,500) to the invested fund. A most favorable time for purchase came in March, 1898, when war with Spain appeared certain, and securities of all kinds dropped in price. The committee concluded to exceed the limits advised by five hundred dollars ($500), and hence purchased two (2) one-thousand-dollar first-mortgage 5 per cent bonds of the Texas Pacific railroad, dated February 1, 1898, and maturing June 1, 2000 A. D., with accrued interest from December 1, 1897, for the sum of nineteen hundred and seventy-six dollars and twenty-five cents ($1,976.25). The interest upon these bonds is payable semi-annually, June 1 and December 1, and as their current market value is now $2,140, and the Society has already received one hundred dollars ($100) interest thereon during the year, the Treasurer is of the opinion that no mistake was made in exceeding the limit set by the Council, and is only sorry that our resources at the time would not permit the investment of an additional thousand.

The "interest" item of $32.98 has accrued to the treasury from the 4 per cent allowed upon monthly balances with the Security Trust Company of Rochester, N. Y., where the Secretary deposits all the proceeds from sales of publications. This sum added to the amount, $275.50, received during the year from investments, makes a total of $308.48, no inconsiderable sum, and largely offsetting the loss of revenue to the Society from those whose names (37) have been dropped from the roll for non-payment of dues during the entire history of the Society.

The receipts from interest have shown a steady increase since the first year of the Society's history, and the following summary exhibits their rate of growth:

Interest receipts	1888–1889..	$16 63
" "	1889–1890..	51 34
" "	1890–1891..	100 32
" "	1891–1892..	102 73
" "	1892–1893..	150 15
" "	1893–1894..	158 96
" "	1894–1895..	170 06
Interest receipts	1895–1896..	191 00
" "	1896–1897..	220 34
" "	1897–1898..	308 48
Total receipts from interest,	1888–1898....	$1,470 01

The detailed operations of the treasury are shown by the following account of receipts and disbursements:

RECEIPTS.

Balance in treasury November 30, 1897			$2,043 08
Fellowship fees 1896 (10)	$100 00		
" " 1897 (37)	370 00		
" " 1898 (162)	1,620 00		
" " 1899 (1)	10 00		
		$2,100 00	
Initiation fees (6)		60 00	
Life commutation fees (6)		600 00	
Interest on investments:			
Tioga Township, Kansas, bonds.	$70 00		
Cosmos Club bonds	87 50		
Tunnelton, Kingwood and Fairchance Railroad bonds	18 00		
Texas Pacific Railroad bonds	100 00		
On deposits in Security Trust Co., Rochester, N. Y., monthly balances.	32 98		
		308 48	
Sales of publications by Secretary, deposited with Security Trust Co., Rochester, N. Y.		419 65	
			3,488 13
Total amount of receipts			$5,531 21

EXPENDITURES.

Total amount of receipts brought forward			$5,531 21
Expenses of Secretary's office:			
Account of administration	$91 10		
Account of Bulletin	112 16		
Allowance (to include ordinary traveling and clerical expenses)	300 00		
		$503 26	
Expenses of Editor's office:			
Account of administration, printing	$2 50		
Allowance (to include personal and office expenses)	160 00		
		162 50	
Expenses of Treasurer's office:			
Account of administration, printing	$4 40		
Account for postage, etc., for five years prior to 1898	100 00		
Account for postage for current year	20 00		
		124 40	
Publication of Bulletin:			
Printing,	$1,112 99		
Engraving	231 91		
		1,344 90	
Photograph account:			
Geo. P. Merrill, expenses		12 50	
Expenses of Librarian		17 55	
Investment account:			
One Texas Pacific Railroad bond, No. 20892, 5 p. ct., $1,000, cost.	$990 00		
One Texas Pacific Railroad bond, No. 11915, 5 p. ct., $1,000, cost.	986 25		
		1,976 25	
Total amount of expenditures			4,141 36
Balance in treasury November 30, 1898			$1,389 85

The following summary exhibits the annual and total receipts and disbursements of the Society during the decade now closing:

RECEIPTS

	Annual dues.	Initiation fees.	Life commutations.	Interest.	Sales of publications.	Sundry acc'ts.	Total.
1888–'89	$1,820 00	....	....	$16 63	.. ..	$0 50	$1,837 13
1889–'90	1,420 00	$40 00	$1,800 00	51 34	....	4 29	3,315 63
1890–'91	1,720 00	190 00	200 00	100 32	$157 35	106 95	2,474 62
1891–'92	2,160 00	160 00	100 00	119 22	426 85	200 94	3,167 01
1892–'93	1,840 00	80 00	....	150 15	598 05	2 00	2,670 20
1893–'94	1,880 00	150 00	100 00	158 96	576 80	10 00	2,875 76
1894–'95	1,910 00	150 00	200 00	170 06	491 50	77 50	2,999 06
1895–'96	1,880 00	120 00	....	191 00	638 45	90 80	2,920 25
1896–'97	1,840 00	140 00	300 00	220 34	821 35	.. ..	3,321 69
1897–'98	2,100 00	60 00	600 00	308 48	419 65	....	3,488 13
Total..	$18,570 00	$1,090 00	$3,300 00	$1,486 50	$4,130 00	$492 98	$29,069 48

EXPENDITURES *

	Administration, Library, and Bulletin distribution.	Maps and photographs.	Publication, including editorial expenses.	Permanent investment.	Total.
1888–'89.........	$181 25	....	....	....	$181 25
1889–'90.........	368 87	$10 00	$1,763 46	....	2,142 33
1890–'91.........	323 58	....	2,691 25	$1,140 26	4,155 09
1891–'92..... ...	514 16	43 83	1,667 68	900 35	3,126 02
1892–'93.........	628 50	11 67	1,886 64	700 00	3,226 81
1893–'94.........	788 58	14 80	2,142 51	....	2,945 89
1894–'95.........	676 00	12 22	1,746 35	304 00	2,738 57
1895–'96.........	632 79	11 95	1,824 09	....	2,468 83
1896–'97.........	707 32	6 18	1,739 98	100 00	2,553 48
1897–'98.........	645 21	12 50	1,507 40	1,976 25	4,141 36
Total.........	$5,466 26	$123 15	$16,969 36	$5,120 86	$27,679 63

Balance on hand, uninvested	$1,389 85

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* The cost of distributing the Bulletin and the other expenses connected with the publication incurred by the Secretary's office are included under "Administration" expenses, in the second column. Since December, 1892, such expenditure for the Bulletin amounts to $1,104.72. For the earlier time the figures are not precise, but the total expense of this kind is about $1,300. Adding this amount to the total of column four would make the total cost of publication $18,269.36, and would reduce the cost of administration to $4,166.26.

The total expenses of the Library have been to date about $67.

The invested funds of the Society are as follows:

On account of publication fund:

April 1, 1891, one Tioga township, Kansas, bond, cost $1,140.26	$1,000 00	
January 29, 1892, eight 5 per cent Cosmos Club bonds at par	800 00	
February 26, 1892, one 5 per cent Cosmos Club bond, with accrued interest, cost $100.35	100 00	
February 3, 1893, seven 5 per cent Cosmos Club bonds at par, cost $700	700 00	
May 1, 1895, two 10–20 gold bonds of Tunnelton, Kingwood and Fairchance railroad, bearing interest from January 1, 1895, cost $204	200 00	
September 27, 1895, one bond of Tunnelton, Kingwood and Fairchance railroad, with interest from July 1, 1895, cost $100	100 00	
January 27, 1897, one 5 per cent Cosmos Club bond, No. 56, first series, cost $100	100 00	
March 17, 1898, one Texas Pacific Railroad bond, No. 20892, 5 per cent, due June 1, 2000, interest payable semi-annually, cost $990	1,000 00	
March 25, 1898, one Texas Pacific Railroad bond, No. 11915, 5 per cent, due June 1, 2000, interest payable semi-annually, cost $986.25	1,000 00	
		$5,000 00

Respectfully submitted.

I. C. White,
Treasurer.

Morgantown, West Virginia, *December 10, 1898.*

Editor's Report.

To the Council of the Geological Society of America:

The publication of volume 9 has been attended with considerable delay and some annoyance to publishing members by reason of the absence of the Editor in Alaska from early March to the middle of October. Although the first brochure of the volume was issued at the usual time, December 30, the last one, owing to the absence above referred to, was not completed until December 1 (1898), instead of April 30, the usual close of the publication year. The delay would have been greater, but for the kindness of Mr J. S. Diller, who generously added to his other burdens that of carrying forward the editorial work, and pages 257 to 452 were printed under his direction.

Although, as just noted, the brochure containing the Proceedings of the Tenth Annual Meeting was not issued as a whole until December 1, 1898, it is due the authors appearing therein to state that "separates" of pages 401 to 452 were printed in July and distributed in September. It is not likely that delay will be again caused by similar conditions, and the attention of members is called to the desire and purpose of the Council to furnish the promptest medium of geological publication to be found in the United States, while the means now at the command of the Society insures the fullest illustration of papers.

Although volume 9 contains 460 pages and is copiously illustrated with 29 full-page half-tone plates and 49 line-work figures, it is the least expensive volume thus far issued by the Society, indicating that due regard has been paid to economy.

The printing of volume 10 is now well under way, and all material sent the Editor has been placed in the printer's hands. Attention is again called to the desirability of preparing an index of the ten volumes issued by the Society during its eleven years of existence. The making of such an index is no small task, and if the Council approves of such a step, plans should be perfected at the Winter Meeting in order that the work may be commenced before volume 10 is completed.

Although exact classification is not attempted, the contents of volumes 7, 8, and 9 are fairly well presented in the following comparative table:

Divisions.	*Vol. 7. Pages.*	*Vol. 8. Pages.*	*Vol. 9. Pages.*
Terminology	1	..	..
Dynamic geology	3	24	85
Economic geology	4	14	16
Relation of geology to pedagogy	12	..	..
Stratigraphic geology	21	67	28
Memoirs of deceased members	28	8	12
Areal geology	38	34	2
Petrology	40	43	44
Physiographic geology	53	5	..
Official matter	56	69	54
Rock decomposition	74	26	17
Glacial geology	105	98	138
Paleontology	123	58	64
Total	558	446	460

The cost of each of the nine volumes thus far issued by the Society is as follows:

	Vol. 1. (pp. 593; pls. 13)	Vol. 2. (pp. 662; pls. 23)	Vol. 3. (pp. 541; pls. 10)	Vol. 4. (pp. 458; pls. 10)	Vol. 5. (pp. 665: pls. 21)
Letter-press	$1,473 77	$1,992 52	$1,535 59	$1,286 39	$1,887 21
Illustrations	291 85	463 65	383 35	173 25	178 40
	$1,765 62	$2,456 17	$1,918 94	$1,459 64	$2,065 61

	Vol. 6. (pp. 528; pls. 27)	Vol 7. (pp. 558; pls. 24)	Vol. 8. (pp. 446; pls. 51)	Vol. 9. (pp. 460; pls. 29)
Letter-press	$1,341 93	$1,463 60	$1,262 22	$1,176 64
Illustrations	221 62	200 24	317 76	231 91
	$1,563 55*	$1,663 84*	$1,579 98	$1,408 55

* The actual cost to the Society was $77.50 less for volume 6, and $90.80 less for volume 7, those amounts being paid by authors for illustrations and correction charges.

Respectfully submitted. JOSEPH STANLEY-BROWN,
Editor.

WASHINGTON, D. C., *December 10, 1898.*

LIBRARIAN'S REPORT.

To the Council of the Geological Society of America:

The Library of the Society is housed on the third floor of the Case Library building, in Cleveland. The space allotted is at present sufficient, but more will be needed the coming year. The extra space and shelving required will no doubt be furnished, the Case Library authorities being disposed to allow us every facility in their power.

The contract with Case Library requires that they shall do all necessary binding; but prior to the appointment of your Librarian, one year ago, little had been done in this respect, the Library authorities not deeming themselves competent to determine what should or should not be bound. The amount of material needing binding was therefore great, amounting to between 350 and 400 volumes. It seemed neither just nor considerate to require the whole to be bound in one year. Of the whole number, 150 volumes have been cared for during the past year, and the whole will be completed within the next two years.

A careful inventory of the Library was made at the time of taking charge, showing nothing to be missing and everything in good order.

Some effort has been made during the past year to complete certain volumes of exchanges which were imperfect. The number was not great, and the immediate and cordial responses most gratifying.

The library comprises at the present time, in approximate numbers:

Bound volumes of Official Geological Surveys	290
Pamphlets of Official Geological Surveys	330
Proceedings of Scientific Societies, bound	223
Proceedings of Scientific Societies, unbound	200
Miscellaneous, mostly separate pamphlets	500

The use of the library is at present limited to those Fellows of the Society who reside in Cleveland, and to such patrons of the Case library as may wish to use it for reference. It is to be regretted that it is not of more service to the Fellows at large. It would seem that there must be a considerable number so situated that they lack access to a large library, and that to such it might be easily made a convenience. Quite possibly a complete list of at least the "foreign exchanges" of the library, in serviceable form, might facilitate such use. At present information concerning the contents of the library is only to be obtained from the lists of additions published annually in the Bulletin.

The Librarian would recommend that the Institute Geologico de Mexico be placed on the "exchange list" of the Society. Aside from the fact that the Society has no exchanges in Mexico, the number and character of the publications sent by that organization to the library of the Society would seem to warrant the procedure.

The expenses of the Librarian's office during the past year are as follows:

Stationery and printing	$3 75
Postage and postal cards	7 91
Rubber stamps	2 75
Freight and expressage	5 64
	$20 05

The last item represents the cost of transferring library material from Rochester to Cleveland. Nearly all such material now comes direct to Cleveland.

Respectfully submitted. H. P. CUSHING,
Librarian.

CLEVELAND, OHIO, *December 1, 1898.*

Upon motion of the Secretary, it was voted to defer consideration of the Council report until Thursday morning.

As the Auditing Committee, to examine the accounts of the Treasurer, the Society elected J. C. Smock and W. H. Holmes.

ELECTION OF OFFICERS

The result of the balloting for officers for 1899, as canvassed by the Council, was announced by the Secretary, and officers were declared elected as follows:

President:

BENJAMIN K. EMERSON, Amherst, Mass.

First Vice-President:

GEORGE M. DAWSON, Ottawa, Ont.

Second Vice-President:

Charles D. Walcott, Washington, D. C.

Secretary:

H. L. Fairchild, Rochester, N. Y.

Treasurer:

I. C. White, Morgantown, W. Va.

Editor:

J. Stanley-Brown, Washington, D. C.

Librarian:

H. P. Cushing, Cleveland, Ohio.

Councilors (term expires in 1901):

W. M. Davis, Cambridge, Mass.
Joseph A. Holmes, Chapel Hill, N. C.

ELECTION OF FELLOWS

The result of the balloting for Fellows, as canvassed by the Council, was announced, and the following persons were declared elected Fellows of the Society:

Alja Robinson Crook, A. B., Ph. D., Evanston, Illinois. Professor of Mineralogy and Petrography in Northwestern University.

Noah Fields Drake, A. M., Ph. D., Tientsin, China. Professor of Geology and Mining in Imperial Tientsin University.

Arthur Hugo Elftman, B. L., A. M., Ph. D., Grand Marais, Minnesota. Mining Engineer.

Myron Leslie Fuller, S. B., Boston, Massachusetts. Assistant in Geology, Massachusetts Institute of Technology.

Amadeus William Grabau, S. B., M. S., Cambridge, Massachusetts. Fellow in Paleontology, Harvard University.

Joseph Hyde Pratt, Ph. B., Ph. D., Chapel Hill, North Carolina. Assistant Geologist, North Carolina Geological Survey.

Frank Clemes Smith, B. S., E. M., Deadwood, South Dakota. Mining Engineer.

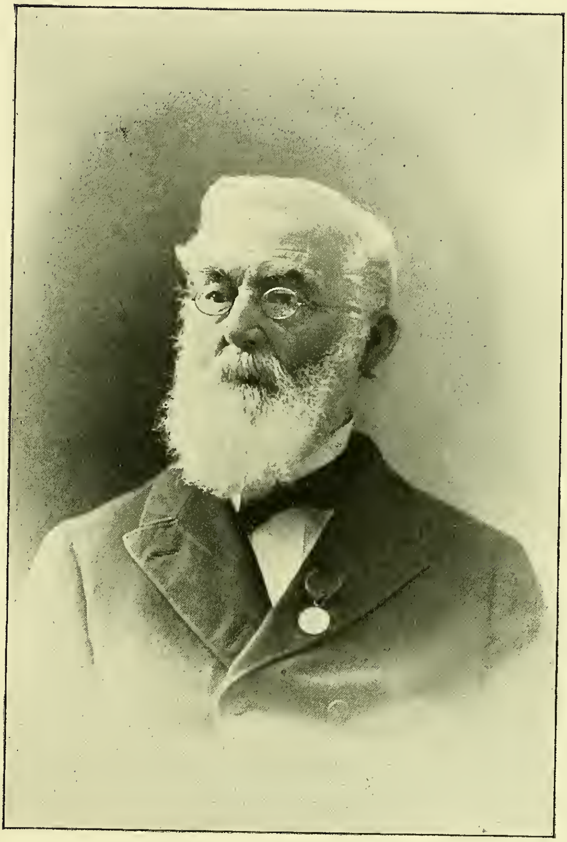
Frank Robertson Van Horn, B. S., M. S., Ph. D., Cleveland, Ohio. Instructor in Geology and Mineralogy, Case School of Applied Science.

Theodore Greely White, Ph. B., A. M., New York, New York. Assistant in Physics in Columbia University.

Samuel Wendell Williston, A. M., M. D., Ph. D., Lawrence, Kansas. Professor of Historical Geology in University of Kansas.

James Hall, 1847

Sincerely Yours
James Hall



James Hall, 1891

Sincerely Yours
James Hall

Announcements concerning certain details of the printed program and of the annual dinner were made by Professor J. F. Kemp and Mr E. O. Hovey.

The following memorial of the first President of the Society was read by the President from the Chair:

MEMOIR OF JAMES HALL

BY JOHN J. STEVENSON *

Professor James Hall, the first President of this Society, was born in Hingham, Massachusetts, September 12, 1811, and died in Echo Hill, Bethlehem, New Hampshire, August 7, 1898.

His father, James Hall, came from England, when only nineteen years old, to spend a year in travel through the United States. On the vessel he met a girl of his own age, Susan Dourdain, who, with her parents, was coming to reside in America. He married her soon after their arrival in Boston, and a rupture of friendly relations with his father followed, so that the young couple were compelled to make their way as best they might. Neither had been fitted by previous training for any such struggle, and poverty was always the lot of the family.

James Hall, the eldest son, was sent to the public school in Hingham, but lost much time, as his assistance was needed for support of the family. He succeeded, however, in obtaining private lessons in Latin and in securing books by doing, as he said, anything and everything. Nothing daunted him. When Silliman delivered the Lowell lectures in Boston, Hall attended them all, though on each occasion he had to walk from Hingham and back again.

His preparation for Rensselaer Institute having been completed, he hardly knew how, he went to Troy, where Eaton was imparting his own enthusiasm to nearly every pupil with whom he came into contact. It was soon discovered that the lad from Massachusetts had not merely a taste, but rather a passion, for natural history, and Eaton himself gained inspiration from him. Each summer was spent in fieldwork, under Eaton's direction, and often in company with Ebenezer Emmons, then an instructor in the Institute. Hall collected nearly nine hundred species of plants while a student and determined them. In geological excursions he reached as far south as the Coal Measures of the anthracite region, and had begun before his graduation that collection of fossil plants which afterwards proved so important.

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* I am indebted to Mrs Thomas B. Bishop, of San Francisco, California, the daughter of Professor Hall, for information which has been used in preparing this memoir. The illustrations originally appeared in Science, and appear here through the courtesy of Professor J. M'K. Cattell, editor of that journal.

He received his degree in 1832. After a visit to the anthracite region of Pennsylvania he had still a little money in his pocket, with which he went to the Helderberg mountains, southwest from Albany, where he spent the summer in elaborating the section and in making collections. In September, when the money was almost gone, he returned on foot across the country to Troy to gather up his books, furniture, and collections, but without any definite notion as to what was to become of him or them. Until he reached his room in Troy the future had concerned him very little; the burdens of the present had sufficed; but as he sat there, with no plan for the future, the sense of absolute loneliness became so oppressive that he could not even pack.

Just then Eaton passed along the hallway and, looking in at the door, said, "Hall, what are you doing?" "Packing my property," was the reply. "Where are you going?" The answer was frank, "I do not know." Eaton urged him to remain, and, when Hall said that he had no money, replied simply, "We can arrange that." The result was that Hall was made librarian, with board and lodging as his compensation. As the library was small, the room assigned for it was very small, but it sufficed to accommodate the library and the librarian for several months. Before the close of the year he was made assistant professor at $600 a year and board, which gave him means for the prosecution of his work.

Eaton's attachment was very noteworthy. He brought his protégé to the attention of Stephen Van Rensselaer, the great patron of science, for whom Hall made explorations in Saint Lawrence county, his first systematic work in geology. This was done so well that when the State Geological Survey was organized, Van Rensselaer endeavored to obtain an independent appointment for Hall; but only four districts were made, and the best that could be secured was an appointment as assistant to Emmons, his colleague, who was thirteen years his senior.

There was little probability that this partnership would be pleasing to either, for each had done work in portions of the district and each held very positive views. Emmons in his annual report failed to make any reference to Hall or his work. Before the season of 1837 the state was redistricted, Mr Conrad withdrawing from the geological work to become the paleontologist. His district was taken by Mr Vanuxem, and Mr Hall succeeded to the fourth district, the level, uninteresting western portion of the state, which he was told was good enough for a young man of twenty-five. From that time his life was bound up in the official work for the state of New York, and after 1843 he was the survey. At the time of his appointment he was younger than any of his colleagues. Vanuxem had reached middle life, Emmons was thirty-eight, Conrad thirty-four, and Mather thirty-three; but some of them were still young enough to feel the importance of their years and to make the youngest member of the corps repent his aggressiveness.

The work in the fourth district was performed with characteristic energy. The region was not the western New York of today; roads were less numerous and less carefully made; exposures were rare and poor. It was necessary to wade along streams for miles to gain fragments which were to be pieced into tentative sections; the people were suspicious, fearing some new scheme for increasing the taxes; but none of these things moved him; as in later years, difficulties only increased his determination. So his is the only one of the four final reports which deals broadly with the problems of the young science, and, though upon the contemned fourth district, it is the only one which has endured with authority and become a classic in geological literature.

While the survey was in progress, Professor Hall, with his colleague, Professor Mather, and some gentlemen in Philadelphia, became interested in the mineral region of southeastern Ohio, where a large area was secured in 1838. Professor Mather soon afterward became a resident of Ohio, though retaining his position on the New York survey, and the property was allotted to the several purchasers, about 2,000 acres falling to Professor Hall. It was practically wilderness land, but studies by Hildreth and Briggs had shown that it lay within the best mineral region of the state, and, as afterward was discovered, Professor Hall's share was the best of the whole. When the fieldwork of the New York survey had been completed, Professor Hall made a journey to the Mississippi valley, partly to see his property, partly to trace the New York formations, and partly to make purchases of mineral lands for some gentlemen in New York. The banking system was uncertain then, and it was necessary to carry the whole sum to be invested sewed into the lining of his clothes.

While on this journey he remained for a few days in the house of Mr Henry Newberry, at Cuyahoga Falls, Ohio, where he became acquainted with John S. Newberry, then a lad of nineteen, who had become an enthusiastic collector of Coal Measures plants from his father's coal mine. He was able to give valuable information to Professor Hall respecting the distribution of the principal beds near Cleveland, which aided materially in determining plans for the journey, while he received in return the generic names of the plants which he had collected. This brief association had its influence on the lives of both. More than once Dr Newberry spoke to me of Hall's extraordinary gentleness and attractiveness, while Professor Hall's face always brightened as he spoke of the guileless boy whom he met at Cuyahoga Falls.

Upon returning to Albany, Professor Hall found Mr Conrad in a decided frame of mind. As paleontologist of the survey, he had found an accumulation of material that seemed too much for a lifetime. "To describe and figure the new species alone would require a great quarto volume with more than one hundred plates," was his moan. The prospect so terrified him that soon afterward he threw off the work and returned to Philadelphia. Mather was already in Ohio and Vanuxem had determined to retire to his farm. Hall and Emmons remained in Albany, desirous of retaining connection with state work that they might continue their studies. They were employed for a time in arranging the mass of material gathered during the survey work. While thus engaged, they discovered that the paleontology would prove even more important than Conrad had imagined. Each determined to be the paleontologist. The contest was hardly what might be termed friendly, but the outcome was that the paleontology was assigned to Hall, while Emmons was commissioned to write up the agriculture, and was appointed custodian or curator of the collections. But the new officials had hardly settled down to hard work when the legislature transferred the collections, or the cabinet of natural history, to the care of the Board of Regents of the University of the State of New York. The secretary of that board removed Doctor Emmons from the curatorship and thrust both of the geologists out of their quarters in the old State house. Soon afterward appropriations for the paleontology were cut off, except, curiously enough, those for the engraving, which were not opposed, but rather favored. At that time was begun a contest between Professor Hall and the board of regents which lasted for a number of years. When the executive officer of the board was changed the relations became friendly again, and so remained for many years.

Expelled from the State house, Professor Hall at once erected a building adjoining his residence, where his work was carried on until 1852, when he removed to a larger house. In 1857, after the state had begun appropriations for collecting fossils, he erected a very commodious brick building, in which the work was done until within a few years of his death. The first volume of the Paleontology was published in 1847 and made a notable impression, though the mechanical execution of the work, as well as the work itself, was far below the standard of later years. The second volume, published in 1852, was a great improvement upon the first, both in matter and manner, but prior to the appearance of the latter volume the state had abandoned further prosecution of the work. Its magnitude had not been foreseen at the beginning, but before the second volume was completed it was clear that the extent could hardly be foretold. This phase was emphasized so strongly by Professor Hall's chief opponent that frugal legislators were induced, in 1850, to cut off all appropriations for current expenses and salaries, though for some reason which does not appear on the surface the engraving contract was cared for and a small appropriation was made for drawings.

The state abandoned the work, but Professor Hall did not. Confident that it would be resumed, he retained his assistants for a time and continued the collecting and drawing until 1855, paying practically the whole cost. Despairing then of any assistance from the state, he accepted the proposition, made years before, by Sir William E. Logan, that he go to Canada as paleontologist with the expectation of becoming head of the survey upon Sir William's retirement in the near future. But, during the five years, Professor Hall had exhausted his cash resources and had incurred obligations which were pressing. A considerable sum of money was needed to pay his debts and to take him to Canada.

There was nothing available except the Ohio land, which he had kept, not to be sold until advancing years should render him unable to work. He always maintained that the property would be very valuable before his sixtieth birthday; but the sale had to be made, and he accepted an offer of $15,000, which enabled him to pay the obligations incurred to continue the work. Ten years afterward the property was valued at $200,000. Had it not been for this sacrifice, the "Paleontology of the State of New York" would have been closed with the second volume, in 1852.

In 1855 the Honorable Elias Leavenworth, then recently elected Secretary of State, learned that Professor Hall had determined to go to Canada. Realizing that to abandon the work in its incomplete condition would be discreditable to the state, he urged Professor Hall to delay, and called a meeting at his house to consider the matter. That meeting was attended by Professor J. D. Dana, Professor Agassiz, Sir William E. Logan, Mr Blatchford, and, among others, by Dr Beck, then, as for many years previously, Secretary of the Board of Regents. At this conference a plan for continuing the work was prepared, Professor Hall consenting to remain in case the legislature confirmed the agreement. The influence of Mr Leavenworth and Mr Blatchford prevailed with the legislature, and Professor Hall remained to carry on the work for 43 years.

I have thought well to dwell somewhat in detail upon these matters. Professor Hall was severely criticised because of the long intervals between the appearance of his second, third, and fourth volumes. Much of the criticism was due, no doubt, to the ignorance of the critics, who appear to have imagined that drawings of fossils can be made as rapidly as sketches of scenery, and that the writing of descriptions involves no more labor than the preparation of a report on a fire for a daily paper. The more intelligent criticism was due to ignorance of the conditions—that the state had abandoned the work, that the office staff had become broken, and that new hands as well as new minds had to be trained; that the work had, as it were, to be begun *de novo*. Even now it is not generally known that the great collections upon which much of the state paleontology is based were made by Professor Hall at his own expense prior to 1856 and very largely at his expense after 1866, the appropriations for collecting as such having continued practically only from 1856 to 1866.

The delay in beginning to publish the volumes after the third was due to exceedingly wise forethought. The work was published fragmentarily, so that results were made available to workers everywhere almost as soon as they were obtained, but the volumes did not appear promptly. Had they appeared promptly, had each division been finished in order, the work could have been stopped at any time; but the drawing and engraving went on for several volumes simultaneously, so that at no time for a number of years was any volume very near completion, but so much work had been done on all that continuation was necessary in order to save what had been expended already. More than once this argument prevailed with an unwilling committee, and the appropriations were ordered. On one occasion a very prominent citizen of New York city told me that there was no longer any use in trying to head off Professor Hall, for "he keeps so far ahead in his work that out of mere shame it is necessary to keep him at it."

The great mass of his publications appeared after he had reached three score years, an age when most men feel that the burdens of life should be lessened. He kept himself young by persistent work, and when eighty-six years old his mind was keen, more ready to accept new ideas and to reject erroneous, though cherished opinions, than when he was but thirty years old.

Professor Hall's energies, however, were not confined to the work in New York. Forty-seven years ago he contributed three important chapters to Foster and Whitney's report on the Lake Superior region; fifty-three years ago he prepared a discussion for Fremont's report, and soon afterward another for Stansbury's. His share of the Mexican Boundary report, published more than forty years ago, occupied 100 quarto pages. In the early fifties he sent Meek and Hayden to the Black Hills region to make collections of vertebrates and invertebrates, thus initiating the great work done afterward in the far west by those explorers. He was state geologist of Iowa and afterward of Wisconsin, meeting in each case with the degree of success which usually attends attempts to direct the survey of one commonwealth while residing in another, though he was able to publish important reports. He contributed an elaborate memoir to the Canada Survey publications. In later years his excursions into other states were confined to paleontological work, much of which was published jointly by himself and Professor R. P. Whitfield, the more important memoirs being those upon Ohio, Kentucky, and the Fortieth Parallel.

At the very outset of his career, when only 21 years old, he succeeded in determining the position of our Pennsylvania anthracites in the geological column. Eaton, in the second edition of his text-book, refers to proofs obtained at Carbondale by his pupils in 1832, showing the American coals, "bituminous and anasphalt," to be equivalent to those of Europe. The study of those fossils was by Hall, who made still further collections of coal plants, and determined 25 species. Eaton referred to this work in 1833 as the joint work of himself and Mr Hall. "It was the intention of Mr Hall and myself to have determined the names of all which had been determined by M. Brogniart, and to have given lithographic figures of the remainder, but we are prevented by other engagements."* At that time Hall was applying his knowledge of recent botany to paleobotany, so that he was enabled to give to Eaton the generalization which had escaped the Pennsylvania geologists, for, according to Lesley, even 3 years later, Taylor and others "drew a sharp distinction in age between Broad Top and Alleghany Mountain coal, and even Rogers expressed a doubt of their identity in an annual report."†

Professor Hall's influence upon American geology began with his reports. One must concede in all fairness that some of Professor Hall's friends in the earlier days gave him rather more credit for the New York state work than was properly his share, much more indeed than he ever claimed, the result being that in the minds of many he is thought to be entitled to the whole credit for the subdivision of the column. Conrad, Vanuxem, Eaton, and Emmons did good work; Conrad and Vanuxem on the survey did great work, which went far toward determining the section. Let us not fail to honor the men who were Hall's associates on that survey. Because they were not great in so many ways as Hall, they fall, as it were, deeply into shadow, and we are liable to overlook their excellence; the more so because nearly every one of them died before the younger generation of geologists were out of swaddling clothes, and to most of us they are but names.

Yet the credit for final, authoritative determination of the column must be given to Hall and to him alone. With the rest he had labored

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*Amer. Jour. Science, vol. xxiii, p. 399.

†Second Geol. Surv. of Pennsylvania, Report A, p. 18.

to subdivide the column on physical grounds. The importance of paleontological confirmation was felt by all, and Conrad had tried to make the confirmation, but the examination of his list of fossils shows how defective his data were. The column thus divided was useful only for direct tracing and afforded nothing for general service. Professor Hall determined the fossils of each division, proved that the formations defined on physical grounds are practically coextensive with those defined on paleontological grounds, and so gave means for identification over broad areas. As this work was done within an offshore region, where changes in conditions were exceptionally numerous and positive, a too rigid application of the New York measuring line led at first to errors of correlation elsewhere; but those errors were inseparable from the times, when all the workers were self-trained and were becoming good geologists only by correcting their own errors.

Conrad was the first in our country to make extended study of Paleozoic fossils, but he soon abandoned the work. For a long time Professor Hall had the field so thoroughly to himself that he came to regard it as his own. For more than half a score of years he resented with great energy and no little acerbity any intrusion upon his domain. His great knowledge of forms, necessarily far beyond that of any other American student, rendered him not sufficiently tolerant of opposing opinions, and too frequently his criticisms had a scornful tone, which secured to him as an inalienable possession the implacable hatred of some of his contemporaries. But the systematic revision of his own work, begun almost two-thirds of a century ago, made its defects so manifest to him as absolutely to change his disposition toward fellow-students in paleontology. As the years went by ill-will toward scientific men who, as he believed, had done him injustice, disappeared; he sought friendship and cooperation where before he had repelled both. There were men for whom to the last he entertained certainly no affection. To have been indifferent toward them would have required him to be either more or less than man, and he was neither.

Professor Hall's thorough method of investigation was all his own, and the laboratory on the Albany hill was a training school for American paleontologists. One after another of his assistants having begun with him at the alphabet of the work went out to hew a special path for himself and to make American science respected. When we think of Meek, White, Whitfield, Walcott, Beecher, and Clarke, we think of American paleontology, for those men have given most of the literature on invertebrate paleontology, aside from that published by Hall himself. He impressed himself upon his assistants while he cultivated in them powers which he did not possess himself. He was a great teacher, for though we can not fail to see his impress in the method of every man who ever labored with him, yet we find the individuality of every man unchanged, so that his independent work is characteristically his own.

As a mere collector, Professor Hall could hardly be surpassed. He knew no duplicates; no two specimens of any species seemed precisely alike. He was one of the first to maintain the danger of mere species-making, and to insist on the gathering of abundant material. When he collected, he collected all there was. He believed in thorough work, whether in collecting or in studying. His first collection, on which was based much of his published work, went to the American Museum of Natural History in New York city, and much of the money obtained for it was expended in gathering another collection of immense bulk.

There is danger of forgetting that Professor Hall was preeminently a geologist. His quartos on the New York paleontology are his monument, and the casual observer is liable to see in him a biologist rather than a geologist; but until his later years he was a geologist. His studies were from the standpoint of one seeking to determine relations between the physical and biological conditions in order to solve problems of correlation. The great problems of geology, not those of biology, were uppermost in his mind until less than twenty years ago. His presidential address to the American Association for the Advancement of Science, in 1857, was so far in advance of the time as to be thought not merely absurd but mystical; yet today it is recognized as one of the most important contributions to one of the most difficult problems in physical geology. Even in his later years, when biological problems had assumed their proper importance for him, he would have resented an intimation that he was any less of geologist than before. When he succeeded in rehabilitating the New York survey, the economic side was not forgotten, and the annual reports presented to the legislature have been of late years as useful from the economic as from the scientific standpoint.

Professor Hall's work received recognition at home and abroad. He was foreign member of the London Geological Society, vice-president of the French Geological Society, correspondent of the Institute, foreign member of the Lincei, and of many other societies and academies. He had received the Wollaston medal and had been decorated by several monarchs. He was vice-president of the Geological Congresses at Paris and Bologna and honorary president of that at Washington. He was a charter member of the National Academy of Sciences and was president of the American Association in 1856. He received the degree of LL. D. from Hamilton College in 1863 and from McGill University in 1884.

As a youth, Professor Hall must have been merry and inclined to cast care to the winds. The old daguerreotype, reproduced here, suggests such a disposition, and Dr Newberry's description of him as a young man of sunny temperament, a delightful and absolutely irresistible companion, is such as one knowing him well in his later days would imagine. The contrast between the countenance of the young man at 35 and that of the old man at four score tells the story of a life filled with conflict. Burdens came early, but they belonged to the normal struggles of a New England youth, and had no effect except perhaps to make him more self-centered. Intimate association in the formative period with men like Eaton and Emmons, the incarnation of dogmatism, must have increased and confirmed a similar tendency in him, but could not have affected his disposition. Had matters run smoothly for half a score of years after the close of the survey, his life might have been an easier one; but he learned almost at once that a friend is a vain thing to lean upon, and soon afterward he was plunged into official conflicts, which lasted in one way or another until within three years of his death.

The fundamental feature of his character was childlike simplicity united to self-confidence and indomitable energy. Simplicity kept him from concealment of his purposes and self-confidence kept him from seeking easy modes of accomplishing them. Knowing what he wanted, he took a direct line, with little regard for anybody or anything which might be in the way to oppose. In early days the Albany officials did not understand him, believing his frankness to be but the cover for craftiness. He deceived his opponents by always telling the truth, something strange to politicians; but in time they came to understand him well, and strong men sought combat simply to measure strength, as in gladiatorial contests of olden time. Almost invariably he was victorious, but victory was often worse than defeat, for it converted into lifelong enemies men who before had been merely indifferent, and so it came about that, as a leading senator once said, "eternal vigilance is the price of Professor Hall's position." He held his place for almost two-thirds of a century through no favor of man, but solely because he refused to be displaced. His influence over governors, comptrollers, secretaries, and legislators was lost for little more than five years during the long period from 1843 to 1898. In bitter contest for years with a bureau of the state government and at times with prominent officials, he was pestered again and again with committees appointed too often not to investigate, but to condemn. With few exceptions, those committees appointed to curse returned to bless. Indeed, as Judge Draper once said, it is probable that Professor Hall drove more investigation committees up the stump than did any other man or group of men in our time.

Absolutely ignorant of the art of lobbying, unwilling or unable to conciliate an adversary, possessing pronounced political principles which he never concealed, this man by sheer force of will compelled men to rise superior to all party calls; so that throughout his career there were men of all shades of political opinion, inside and outside of the legislature, who held the preservation of his work to be a matter of supreme necessity for the welfare of the state.

But contests such as these, beginning in his early manhood, did not leave him unscarred. Surrounded by men hating him for his success, harassed by men anxious to reap the harvest which he had sowed, his life became one continuous anxiety. In later years his political and official foes were reinforced by others, who seemed to feel that he had done injustice to the world by living too long and thereby securing more than his share of profit. It is not strange that he was often stern and forbidding, carrying into scientific disputes the manner which was his wont when dealing with official adversaries; but it was easy to find the man if only one would, for in personal relations he gave his confidence as freely and affectionately as a child.

Take him all in all, Professor Hall was a great man. His excellencies were towering, his faults glaring. Transparent as crystal, his course was frank, open, and his word as good as a bond. His friends would do anything for him; his enemies would do anything against him. No one knowing him remained indifferent. For a friend he would sacrifice his own interests at any time. He was every read to crush an enemy in the abstract, but the enemy in the concrete, if needing assistance, could find no readier helper than he. Years of bitter aspersion were forgotten more than once when a slanderer became needy, and Professor Hall was quick to risk his own in rendering aid. He knew well how to distinguish between friend and flatterer. The wounds of a friend were never resented. He never desired his friends, in proof of friendship, to share in his enmities. He was a manly man, with a single aim throughout his life. Like a sturdy knight of medieval times, he kept his face toward the goal, turning neither to the right nor to the left—one of the grandest and most picturesque figures in the history of our science.

As he lived, so he died, self-reliant to the last. In 1897, at Saint Petersburg, he said that he intended to send his likeness to me in a gold frame, but not at once, as it would seem too much like the last farewell. During the winter of 1897–1898 he had several severe attacks of vertigo, and in the spring he wrote that there were evidences of giving way, such as to convince him that the work might not go on much longer. In July he must have felt that the end was approaching, for he sent the likeness on the plate of gold just as he left Albany for Echo Hill.

Though in good spirits and apparently in reasonably good physical condition when leaving Albany, he was stricken by vertigo soon after arriving at the hotel. This attack left him so enfeebled that the local physician urged his return to Albany. He refused, preferring to remain where he was and to await the end, which was likely to come suddenly. His letters gave no intimation of the conditions, but were written as calmly as though life were but beginning. Affairs of the survey received his attention in detail, and a long letter respecting them was written only two days before his death, when he was confined to his bed.

The end came as he appears to have expected. On Sunday afternoon, August 7, a servant carried a cup of beef tea to him and placed it near his bed. As she left the room she heard a crash, and, returning, found him lying on the floor beside the bed, dead. The effort to take the cup from the chair had brought on cerebral apoplexy, causing immediate and painless death. He lies buried in Albany, New York.

In 1843 Professor Hall married Susan, daughter of John Aiken, a lawyer of Troy, New York. She died April 25, 1895. Four children, two daughters and two sons, survive him.

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118. Observations upon some of the Brachiopoda, with reference to the characters of the genera *Cryptonella*, *Centronella*, *Meristella*, *Trematospira*, *Rhynchospira*, *Retzia*, *Leptocœlia*, and other allied forms: *Ibid.*, pp. 38–61.
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141. Descriptions of some new species of Crinoidea and other fossils from the lower Silurian strata of the age of the Hudson River group and Trenton limestone, 17 pp.; printed in advance from the Report of the State Cabinet for 1866, Albany, 1866; also published in the Twenty-fourth Report, 1872.
142. Observations upon some species of Spirifera, being the concluding remarks of the chapter on the descriptions of species of that genus from the Upper Helderberg, Hamilton, and Chemung groups: From the Palæontology of New York, vol. iv, pp. 252–257, unpublished; *Proc. Am. Phil. Soc.*, vol. x, Philadelphia, 1866, pp. 246–254.
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147. *Observations on the structure and mode of growth of the spines on the cardinal area of Chonetes, with remarks on the distribution of some species of the genus: *Ibid.*, p. 105.
148. *On the structure of the spires in the genera *Athyris*, *Meristella*, and other genera of Spiriferidæ: *Ibid.*, p. 105.
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152. The genus *Chonetes: Ibid.*, pp. 242–244.
153. Reports on the genera *Productus*, *Strophalosia*, *Aulosteges*, and *Productella: Ibid.*, pp. 245–250.

154. On the genera *Spirifera*, *Cyrtina*, and allied genera: *Ibid.*, pp. 251–257.
155. On the genera *Athyris*, *Merista*, and *Meristella*: *Ibid.*, pp. 258–266.
156. Note upon the genus *Zygospira* and its relations to *Atrypa*: *Ibid.*, pp. 267–268.
157. Remarks upon the genera *Rhynchonella* and *Leiorhynchus*: *Ibid.*, pp. 269–273.
158. Note on the genus *Eichwaldia*: *Ibid.*, pp. 274–278.
159. On the genus *Tropidoleptus*: *Ibid.*, pp. 279–281.
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161. Account of some new or little-known species of fossils from rocks of the age of the Niagara group (originally printed in advance for the Eighteenth Report in the New York State Cabinet, 1864): *Ibid.*, pp. 305–401, 15 pls.
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164. *On the genera *Pentamerus* and *Stricklandinia*, and their supposed relations with Rensselaeria: *Ibid.*, p. 273.
165. *On the genera *Terebratula*, *Centronella*, *Cryptonella*, etc.: *Ibid.*, p. 279.
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168. *Descriptions of Bryozoa, etc., from the Upper Helderberg and Hamilton groups of New York: *Ibid.*, p. 304 (published in *Trans. Alb. Inst.*, 1882).
169. *Miscellaneous notices: *Ibid.*, p. 304.
170. *On the geological relations of the mastodon and fossil elephant (see Twenty-first Report on the State Cabinet of Natural History, Albany, 1871): *Am. Assoc. Adv. Sci.*, 16th meeting (Burlington, 1867), Cambridge, 1868, p. 161.
171. *On the geographical distribution of the sediments and of the fossils in the Hamilton, Portage, and Chemung groups of New York: *Ibid.*, p. 161.
172. *On the value of the term Hudson River group in geological nomenclature (see also for printed notes Proceedings Nashville Meeting, Am. Assoc. Adv. Sci., 1877): *Ibid.*, p. 161.
173. *On the occurrence of fossil sponges in the successive groups of the Palæozoic series: *Ibid.*, p. 161.
174. Geological history of the North American continent; a lecture delivered before the American Institute in New York (Albany, 1869), 24 pp.
175. *Preliminary notice of the Lamellibranchiata of the Upper Helderberg, Hamilton, and Chemung groups: *Proc. Am. Assoc. Adv. Sci.*, 18th meeting (Salem, 1869), Cambridge, 1870, p. 282.
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179. *On the relation of the Oneonta sandstone and Montrose sandstone of Vanuxem to the Hamilton and Chemung groups: *Ibid.*, p. 362.
180. *Note upon the rocks of the Huronian system on the peninsula of Michigan: *Ibid.*, p. 362.
181. *Remarks on the occurrence of the genus *Dithyrocaris* in the Hamilton and Chemung rocks of New York: *Ibid.*, p. 363.
182. Notes and observations on the Cohoes mastodon: *Twenty-first Ann. Rept. N. Y. State Cab. Nat. Hist.*, 1868, Albany, 1871, pp. 99–148 and maps.
183. *Remarks upon the Catskill red sandstone group as it occurs upon the borders of New York and Pennsylvania: *Proc. Am. Assoc. Adv. Sci.*, 20th meeting (Indianapolis, 1871), Cambridge, 1872, p. 418.
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192. Report on fossil trees of Schoharie county: *Ibid.*, pp. 15, 16.
193. Remarks on some peculiar impressions on sandstone of the Chemung group, New York. J. Hall and R. P. Whitfield: *Ibid.*, pp. 201–204.
194. Descriptions of new species of Crinoidea and other fossils from strata of the age of the Hudson River group and Trenton limestone (in part previously published in 1866): *Ibid.*, pp. 205–224, 3 pls.
195. Descriptions of new species of fossils from the Hudson River group, in the vicinity of Cincinnati, Ohio: *Ibid.*, pp. 225–232, 1 pl. (published October, 1871, in advance of the State Cab. Rept.).
196. *On the occurrence of trunks of *Psaronius* in an erect position, resting on their original bed, in rocks of Devonian age in the state of New York, with some inferences regarding the condition of the sea bottom and shoreline during the deposition of the strata: Report of the *British Association for the Advancement of Science*, 42d meeting (Brighton, 1872), London, 1873, p. 103.
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200. The Anderson School of Natural History and Geology of Penikese Island: Field meeting Albany Institute, Albany, 1874, 4 pp.
201. Descriptions of new species Goniatitidæ, with a list of previously described species: *Twenty-seventh Ann. Rept. N. Y. State Mus. Nat. Hist.*, Albany, 1875, pp. 132–136; (also published in advance, 1874).
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204. *Note upon the geological position of the serpentine limestone of northern New York and an inquiry regarding the relations of this limestone to the Eozoön limestone of Canada: *Proc. Am. Assoc. Adv. Sci.*, 25th meeting (Buffalo, 1876), Salem, 1877, p. 385; published in *American Journal*, 3d ser., vol. 12, 1876, pp. 298–300.
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213. *On the present condition of the work upon the palæontology of New York: *Ibid.*, p. 488.
214. Corals and Bryozoans of the Lower Helderberg group: *Thirty-second Ann. Rept. N. Y. State Museum Nat. Hist.*, Albany, 1879, pp. 141–176; also published separately and distributed in 1880, Albany, 1880, 38 pp.

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221. Contributions to the geological history of the American continent: Address of the retiring president delivered before the first Montreal meeting of the American Association for the Advancement of Science, August, 1857 (see No. 59), with notes by James Hall and T. S. Hunt, Salem, 1882.
222. * Note upon the genus *Plumalina* [*Plumalites* in error]: *Proc. Am. Assoc. Adv. Sci.*, 31st meeting (Montreal, 1882), Salem, 1883, p. 419.
223. On the relation of Dictyophyton, Phragmodictyum, and similar forms with Uphantænia: *Ibid.*, p. 419.
224. Van Cleve's fossil corals. Indiana Department of Geology and Natural History: *Twelfth Annual Report for 1882*, Indianapolis, 1883, pp. 239–270, 14 pls.
225. Descriptions of fossil corals from the Niagara and Upper Helderberg groups of Indiana: *Ibid.*, pp. 271–318, 14 pls. (Same as 219, with some revision and the addition of the plates; also republished with lithographed plates in *Thirty-fifth Ann. Rept. N. Y. State Mus. Nat. Hist.*, 1884.)
226. Spergen Hill fossils: *Ibid.*, pp. 319–375, 4 pls. (Same as 131, with additional notes and the four plates which are reproduced from *Bull. No. 3, Am. Mus. Nat. Hist.*, 1882.)
227. Discussion upon the manner of growth, variation of form, and characters of the genus *Fenestella* and its relations to Hemitrypa, Polypora, Retepora, Cryptopora, etc.: *Second Rept. of the State Geologist for 1882*, Albany, 1883, pp. 5–16.
228. Fossil corals and Bryozoans of the Lower Helderberg group and fossil Bryozoans of the Upper Helderberg group: *Ibid.*, pls. 1–33 and interleaved explanations.
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230. Preliminary notice of the Lamellibranchiate shells of the Upper Helderberg, Hamilton, and Chemung groups (preparatory for the Palæontology of New York). Part i (see No. 176): *Thirty-fifth Ann. Rept. N. Y. State Mus. Nat. Hist.*, Albany, 1884, pp. 215–406 G (also published separately, with 5 plates additional).

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233. On the structure of the shell in the genus *Orthis: Ibid.*, pp. 73–75, pls. 3, 4 (also published separately).
234. Descriptions of a new species of *Stylonurus* from the Catskill group: *Ibid.*, pp. 76, 77, 1 pl. (also published separately).
235. Illustration of Cryptozoon: *Ibid.*, pl. 6 and explanation (also published separately).
236. Some new plant forms lately found in the Peach Bottom slates of southeastern York and southern Lancaster counties: *Trans. Am. Inst. of Mining Engineers*, Troy meeting, 1883, 2 pp., 3 pls., 1884.
237. Preliminary note on the microscopic shell structure of the Palæozoic Brachiopoda: *Proc. Am. Assoc. Adv. Sci.*, 32d meeting (Minneapolis, 1883), Salem, 1884, pp. 266–268.
238. Note on the Eurypteridæ of the Devonian and Carboniferous formations of Pennsylvania. Second Geological Survey of Pennsylvania: *Report of Progress*, PPP, Harrisburg, 1884, pp. 23–39, 6 pls. (also published separately).
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240. Descriptions of the Bryozoans of the Hamilton group (Fenestellidæ excepted): *Third Report of the State Geologist for 1883*, Albany, 1884, pp. 5–61.
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243. On the mode of growth and relations of the Fenestellidæ (continuation of No. 226): *Fourth Report of the State Geologist for 1884*, Albany, 1885, pp. 35–45, 2 pls.
244. Note (on some Palæozoic pectenoid shells): *Report State Geologist for 1884*, Albany, 1885, pp. 47, 48; figs. 1–6, p. 46.
245. On the relations of the genera *Strictopora*, *Ptilodictya*, *Acrogenia*, and allied forms in the Palæozoic rocks of New York: *Report State Geologist for 1884*, Albany, 1885, p. 46, figs. 1–6.
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247. Plates and explanations, published in advance of Palæontology of New York, vol. vi, pls. xxv, xxvii, xxix, xxx–xxxii, xl, xli, xliv, xlv, xlviii, l, li, liii: *Fifth Ann. Rept. State Geologist*, 1886.
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254. Palæontology of New York, vol. vii, extract from supplement (Pteropoda and Annelida): Albany, 1888, pp. 1–24, pls. cxiv–cxvi*a*.
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262. A geological map of the state of New York: *Trans. Am. Inst. Mining Engineers*, Plattsburg meeting, October, 1892, pp. 1–7.
263. Review of "A catalogue of North American Crustacea confined to the non-trilobitic genera and species, by A. W. Vogdes": *The Financial and Mining Record*, February 22, 1890.
264. An introduction to the study of the Brachiopoda, intended as a handbook for the use of students. Part 1. James Hall, assisted by J. M. Clarke: *Eleventh Ann. Rept. New York State Geologist*, pp. 128–300, pls. 1–22, 1892.
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266. Preliminary geologic map of New York, exhibiting the structure of the state so far as known. Prepared under the direction of James Hall, state geologist, by W J McGee, 1894.
267. The new species of Brachiopoda described in Palæontology of New York, vol. viii, parts 1 and 2. James Hall, assisted by J. M. Clarke: *Fourteenth Ann. Rept. State Geologist*, pp. 323–402, pls. 1–14, 1895.

The presentation of scientific papers was introduced by the annual address of the President, entitled :

OUR SOCIETY

BY THE PRESIDENT, JOHN J. STEVENSON

This address is printed as pages 83–98 of this volume; also in Science, volume ix, pages 41–52.

Following the President's address the second paper of the program was read :

ARCHEAN-POTSDAM CONTACT IN THE VICINITY OF MANITOU, COLORADO

BY W. O. CROSBY

This paper is printed as pages 141–164 of this volume.

The Society adjourned for lunch and reconvened at 2.15 o'clock p m. In the absence of President Stevenson, First Vice-President Emerson occupied the chair during the afternoon session. The first paper of this session was

OUTLINE OF THE GEOLOGY OF HUDSONS BAY AND STRAIT

BY ROBERT BELL

Remarks were made by the chairman and by J. B. Tyrrell, David White, and H. S. Williams.

The next paper was

UPPER ORDOVICIAN FAUNAS IN LAKE CHAMPLAIN VALLEY

BY THEODORE G. WHITE

Contents

INTRODUCTION

This paper is a preliminary study of the faunas contained in strata of the Black River, Trenton, and Utica formations in the valley in which lake Champlain lies.

Comparatively little attention has been given to the paleontology of the region until quite recently, but the field is one which affords unusually good opportunities for the study of the entire Ordovician series from the base of the Calciferous to an horizon which is at least well up toward the top of the Utica slates. The metamorphism which a short distance from the lake on the Vermont side nearly obliterated the fossil contents of the rocks did not extend to the edge of the lake in most cases. This is contrary to the impression which might be gained from the legend employed on the large wall-map of the state by Professor Hall and Mr McGee (1894). On both lake shores are numerous localities where the low-dipping strata abound in remains of organisms and afford excellent advantages for the study of a continuous section.

The results in the present paper represent the summary of a detailed laboratory examination of a mass of material, aggregating several tons in weight, collected at the localities described during the summers from 1893 to 1896, inclusive, and now deposited in the geological museum of Columbia University.

In the early period of the organization of the New York state geological survey but little attention was devoted to the details of stratigraphy or enumerations of the fossils contained in the formations which comprised the "Champlain division" of the New York system before that divisional designation was transferred to the upper portion of the geological column. Volume I of the Palæontology of New York mentions but 16 fossil species from the three formations under consideration, in the Champlain valley, 4 from the Black River zone, 12 from the Trenton, and none from the Utica or the Hudson. The 1861 report on the Geology of Vermont enumerates 32 Trenton and 5 Utica species. Our investigations to date, in the localities enumerated in the present contribution, show more than 100 species, exclusive of corals, bryozoa, and ostracods, of each of which groups there are many representatives, and which are now in the hands of Mr E. O. Ulrich for identification.

The close detailed work of Logan, published in the 1863 report on the geology of Canada, added much information regarding the stratigraphy of the northern end of the lake. The papers of Marcou,* in connection with the Cambrian and Taconic controversies, and the theory of precursory "colonies," have increased our knowledge of several of the Ordovician localities. More recently the papers of Walcott,† Whitfield,‡ Brainerd and Seely,§ Kemp,‖ Cushing,¶ Ells,** and Ami †† have largely

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*J. Marcou: Bull. Soc. Géol. France, 3d ser., vol. xi, 1883, pp. 407–435; Mem. Boston Soc. Nat. Hist., vol. iv, 1888, pp. 105–131; Proc. Amer. Acad., vol. xx, 1885, pp. 174–256.

†C. D. Walcott: Bull. 30, U. S. Geological Survey, 1886; Am. Jour. Sci., 3d ser., vol. xxxiii, 1888, pp. 229–242, 307–327, 394–401; Am. Jour. Sci., 3d ser., vol. xxxix, 1890, pp. 101–115; Bull. 81, U. S. Geological Survey, 1891.

‡R. P. Whitfield: Bull. Amer. Mus. Nat. Hist., vol. i, 1886, pp. 293–345; Ibid., vol. ii, 1889, pp. 41–63; Ibid., vol. iii, 1890, pp. 25–39; Bull. Geol. Soc. Am., vol. i, 1890, pp. 514, 515; Ibid., vol. ix, 1897, pp. 177–184.

§E. Brainerd and H. M. Seely: Am. Geologist, vol. ii, 1888, pp. 323–330; Bull. Geol. Soc. Am., vol. i, 1890, pp. 501–511: Ibid., vol. ii, 1891, pp. 293–300; Bull. Am. Mus. Nat. Hist., vol. iii, 1890, pp. 1–23; Ibid., vol. viii, 1896, pp. 305–315.

‖J. F. Kemp: Bull. 107, U. S. Geological Survey, 1893; Rept. State Geologist N. Y. for 1893 (1894), pp. 433–472; Fifteenth Ann. Rept. New York State Geologist, 1895, pp. 576–614; Bull. N. Y. State Mus., vol. iii, 1895, pp. 322–355.

¶H. C. Cushing: Ann. Rept. New York State Geologist for 1893 (1894), pp. 473–489; Bull. Geol. Soc. Amer., vol. vi, 1895, pp. 285–296; Fifteenth Ann. Rept. New York State Geologist, 1895, pp. 499–573.

**R. W. Ells: Ann. Rept. Geol. Survey Canada, vol. vii, 1896, pp. 15J–37J.

††H. H. Ami: Ann Rept. Geol. Survey Canada, vol vii, 1896, pp. 113J–157J; Ottawa Naturalist, vol ix, 1896, pp. 215, 216.

added to our information of the distribution of each of the formations within the Champlain valley, and extended the detailed stratigraphic study of the lower members of the formations there so extensively developed.

Scope of the Investigation

As above cited, the detailed stratigraphy of the Cambrian, especially in the northern part of the Champlain valley, has been published by Mr Walcott, while similar work has been done in subdividing the zones of the Calciferous and Chazy in the region by Messrs Brainerd and Seely. My endeavor has been to prepare a similar preliminary study of the detailed stratigraphy of the Birdseye, Black River, and Utica formations overlying the latter.

The method of investigation employed was modeled on that developed by Professor H. S. Williams in his studies of the Devonian of western New York* and which has been described elsewhere by the writer.† Each stratigraphic zone which differed in anywise from those adjoining it was analyzed, on a faunal basis, and kept separate through all subsequent laboratory examination. The mass of the detailed work as thus analyzed will be published in volume xiii of the Annals of the New York Academy of Sciences, and the present contribution is but a summary of results therein set forth. In some cases as many as 96 distinctive beds were recognized and differentiated by reason of faunal or lithologic differences within the limits of a section having a total thickness of less than 200 feet.

General Relations of the sedimentary Rocks of the Region

From Fort Ticonderoga to the head of Missisquoi bay, lake Champlain is about 110 miles long, and its greatest width is 13 miles. The lower Cambrian is unknown on the western side of the lake, but on the eastern has a thickness of many thousand feet. The Calciferous has a thickness of possibly over 1,200 feet, and the Chazy perhaps half that. Following this very considerable mass of deposits, the upper Ordovician beds were laid down, more or less conformably, and all have subsequently undergone not only profound faulting into great blocks, but also local dislocation.

The Birdseye is not clearly recognizable in the Champlain valley itself. Most of the localities and fossils once referred to it in the district are now known to belong to the Calciferous and Chazy. In Benson an outcrop 6 feet thick occurs which contains true *Tetradium cellulosum* (Hall).

Outliers and embayments of the Potsdam and Calciferous are known at an altitude of over 1,000 feet above the lake level, in the midst of the Adirondacks, isolated from the main outcrops, and showing no higher strata above them.‡

Character of the Deposits

The lowest bed of the Black River, wherever a complete section is exposed, is a very compact and tough dove-gray limestone, having a conchoidal fracture, and in appearance somewhat resembling the true Birdseye, but usually containing no fossils other than ostracods. The capping bed of the underlying Chazy, where

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* H. S. Williams: Bull. 41, U. S. Geological Survey, 1887.

† T. G. White and G. van Ingen: Trans. New York Acad. Sci., vol. xv, 1895, pp. 19–23.

‡ J. F. Kemp: Bull. Geol. Soc. Am., vol. 8, 1896, pp. 408–412.

well exposed, seems to be a very constant and characteristic layer of fine grained sandstone or quartzite. It is particularly well shown at Valcour and Crown point,* and seems to indicate a retreating sea at the close of the period immediately preceding the deposition of the Black River strata. The succeeding Black River beds are of heavy bedded black limestone having thin shaly partings, and ordinarily in the upper portion of each distinct thick layer a fossiliferous zone.

The change to beds carrying a true Trenton fauna is usually abrupt, the latter formation consisting of much more thinly bedded and usually softer black limestones and slates. A great variation in the character of these beds is observable, and in consequence the limits of particular conditions which favored the development of particular species is very much more marked than in the Trenton Falls paleontologic province, which was studied by the writer in connection with the present investigation.† In the Champlain Trenton, beds of tough and almost barren black limestone, or similar limestones containing fossils preserved almost entire, are succeeded by far softer beds in which all the contained fossils are entirely fragmentary.

The frequent lenticular character of the limestones is a marked characteristic. These lenses usually consist of a gray, finely crystalline, almost saccharoidal, limestone, usually very fossiliferous, within layers of black slate. The rich fauna of these granular layers is no doubt due to more numerous currents, and certain species, such as *Zygospira exigua* and *Z. recurvirostris*, *Tetradium fibratum*, *Platystrophia biforata*, *Bucania punctifrons*, *Conradella compressa*, *Holopea paludiniformis*, *Bathyurus spiniger*, and *Ceraurus pleurexanthemus*, seem to be almost wholly confined to deposits of this kind.

On the other hand, a large assemblage of linguloid species, *Parastrophia hemiplicata*, most of the lamellibranchs (as might be expected), *Protowarthia cancellata*, *Isotelus gigas*, and *Trinucleus concentricus*, were almost wholly denizens of the mud and are found principally in the shaly portions of the rock. Toward the upper portion of the series, the changes of the sea bottom evidently became a great deal more rapid and increasingly shaly layers appear, with attenuated fine crystalline lenses between.

In several instances, notably on Crown point (Fort Frederick), occur thin, tough, black, fine grained, highly carbonaceous layers, which appear to be the consolidated black mud of perhaps decaying organic remains. The upper surfaces of such layers are highly polished, but this may either have been the result of wear before subsequent deposition took place, or the result of the slip or "slickensides" from movement of the overlying layers on the more slippery surface. Such layers are constant over considerable areas. Many layers, especially those of gray crystalline limestone, are conglomeratic, containing rounded or elongated pebbles and masses of what was evidently thick black mud worn from neighboring land surfaces and entombed. Similar intraformational conglomerates are noted from the Galena series of Minnesota.†

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*J. D. Dana: Discoveries of Reverend A. Wing; Am. Jour. Sci., 3d ser., vol. xiii, p. 415. E. Brainerd and H. M. Seely: Bull. Am. Mus. Nat. Hist., vol. viii, p. 315.

†See T. G. White: Trans. New York Acad. Sci., vol. xv, 1896, pp. 71–96, and Am. Jour. Sci., 3d ser., vol. ii, 1896, pp. 430–432; also C. S. Prosser and E. R. Cummings, Fifteenth Ann. Rept. New York State Geologist, 1898, pp. 615–659.

‡F. W. Sardeson: American Geologist, vol. xxii, 1898, pp. 315–323.

The shales which formed the transition to the Utica must have been very soft and therefore have been eroded away very readily, for nowhere have the transition beds between these two formations been found in position, whereas in several cases where the succession of the series would lead us to expect to find them a filled-in brook channel, beach, or fault will be found to intervene.

The Utica slates have a thickness of several hundred feet throughout the valley, and are quite uniformly of a rather soft friable character and the contained fauna composed of small sized individuals. These rocks have suffered more from dynamic metamorphism than those of the formations beneath.

The early reports were inclined to consider the Hudson River group as being largely represented in the region. Most of the strata once referred to the group are now known to be of Cambrian age. The islands in the lake referred to the Hudson by the Vermont survey have in several cases proved to belong to the Calciferous. We nowhere found fossils which might be considered typical of the Hudson, such as *Pterinea demissa* (Conrad), *Catazyga erratica* Hall, *Dalmanella emacerata* Hall, *Cyrtolites ornatus* Conrad, *Modiolopsis curta* Hall, nor any of the graptolites referred to that group by Lapworth,* while all the fossils found in the upper strata were of well known Utica facies. Professors Brainerd and Seely, at Shoreham, and Mr Walcott, at Highgate Springs, employed the term "Hudson" for the upper portion of the slates, simply because the thickness represented seemed to be greater than that usually assigned to the Utica alone, and no fossils were found by them. On Cumberland head and Grand isle, however, we found a thickness of strata probably fully as great, which contained scattered Utica fossils throughout. Erosion and glacial plowing has no doubt removed a great thickness of deposits, but even the elevated "outliers" already referred to give no indication that strata superior to the Utica were deposited in the district.

At numerous localities the rock is under stress and conchoidally fracturing chips of the tougher limestone fly off under a comparatively light blow of the hammer.

SUMMARY OF THE SECTIONS EXAMINED

IN GENERAL

As already stated, the detailed faunal lists for each section will be published elsewhere. It is therefore only necessary here to give an idea of the completeness of the sections studied before summarizing the faunal lists.

LARRABEE POINT

The most southerly section is that at Larrabee point, Addison county, Vermont, nearly opposite historic fort Ticonderoga. A nearly continuous section is here presented in a small abandoned quarry and along the shore, with a general dip of 10 degrees north. Over 40 feet of Calciferous and Chazy limestones occur in proximity to the base of the section, but the transition beds to the base of the Black River are not shown. The section begins with 12 feet of compact black limestone, with shaly partings, the fossil contents of which indicate that it belongs to the top of the Black River or the lower Trenton.

The entire section is nearly 110 feet thick, and terminates in the Trenton, al-

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*C. Lapworth: Trans. Roy. Soc. Canada, vol. iv, sec. iv, 1887, pp. 167-184.

though a separate outcrop of 15 feet of Utica strata occurs a short distance to the north; also on the opposite side of the lake at Addison Junction, New York.

SHOREHAM

East of Larrabee point there are no important outcrops until Shoreham is reached, about 3½ miles west of the lake. The ridges of strata here exposed embrace the entire lower Ordovician.* They are much sheared and crushed, although retaining remnants of a fauna which was very abundant and which corresponds in the upper portion to that of the base of the Larrabee Point section.

CROWN POINT

The extreme end of Crown point, Essex county, New York, 12½ miles north of Larrabee point, affords the next and for detailed study the most satisfactory section. All four divisions of the Calciferous, as classified by Messrs Brainerd and Seely, overlie the Cambrian with a thickness of 350 feet, followed by all three divisions of the Chazy, aggregating 305 feet thick. The latter terminates within the old French fort (Fort Frederick) near the end of the point, with a bed of silicious sandstone or quartzite, which is also seen at Valcour, at the upper end of the lake. The Black River here attains a thickness of 71 feet 3 inches and contains an abundant fauna. Following this series a beach covers 30 feet of horizontal distance and the transition beds to the Trenton proper, although if no fault occurs in the interval the missing thickness, as calculated on the dip of 8 degrees north 40 degrees west, is only 4 feet. Above the Black River a continuous series of 100 feet of alternating compact, sandy and shaly layers, all quite thin, is presented, which affords constant faunal variations and numerous interesting assemblages of forms. Nearly the entire middle and lower Trenton fauna of the region is represented in this section. After disappearing under the lake, which is very narrow at this point, the Trenton reappears, with beds belonging an unknown distance above the former, followed by the Utica slates, but separated from them, however, by superficial deposits. The Utica slates may be followed in outcrops at intervals for 8 miles along the Vermont shore north of this locality, to Arnold bay in Panton. A little over 2 miles north again on Button island, near Vergennes, Vermont, is a remarkable exposure of the Black River. In the lower portion of the section is a thin band containing myriads of *Leperditia fabulites* in perfect state of preservation, and near the top a sharply defined coral reef band made up entirely of *Columnaria alveolata* and *Stromatocerium rugosum*. The Trenton is exposed in small outcrops on the neighboring shore, and the Utica on Otter river, between the lake and Vergennes, but no continuous section is afforded.

PLATTSBURG AND CUMBERLAND HEAD

On Crab island, nearly opposite the hotel Champlain, beds of the middle Trenton, having a thickness of nearly 100 feet, are shown containing a fauna, among which *Isotelus gigas* and several species of *Endoceras* occur in prolific quantities and of large size. This series of beds, extending up into the Utica, reappears on the shore just south of Plattsburg, although on account of faulting no complete section can be obtained.

Beginning at the head of Cumberland bay, and extending all the way around Cumberland head and thence up the shore around Point-au-Roche is a series of

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* E. Brainerd and H. M. Seely: Bull. Am. Mus. Nat. Hist., vol. iii, 1890, pp. 3–5.

thin bedded shales and limestones containing an interesting fauna, which seems to be transitionary between the Trenton and Utica formations, and also to commingle the fossil forms of the New York Trenton with those of the Canadian formations described by Billings.

The outcrops along the eastern shore occur on successive promontories which seem to be the result of a series of plications of the strata which curve on one side and on the outer side have fractured with more or less sharp faults. The beds differ greatly in hardness, and both differential erosion and differential shearing are seen in them in consequence.

Owing to the great variation of the dips and strikes following the plications of the strata, and owing also to the numerous faults, all of which have been followed out and plotted on the map, which will appear in the full report, it is yet impossible to arrive at the exact thickness and relations of these beds. On the northeastern side of Cumberland head a long, unfaulted, although considerably metamorphosed, continuous section occurs, which measures 457 feet in thickness, but this seems to be but the upper portion of the series. The latter series of beds reappears on Grand isle, exactly opposite this locality, but not so great a thickness is exposed there.

Long point and Short point, the two southern peninsulas of Point-au-Roche, are two north and south anticlinal folds of these same strata.

GRAND ISLE

At the southern end of South Hero, Grand isle, is an extensive, transversely eroded, north and south anticline, which exhibits in series, beginning with the top of the Calciferous, the entire section of the Chazy, 315 feet in thickness, followed, after an interval, by 35 feet of Black River strata, and, after another interval, by 23 feet of the lower Trenton beds.

CHAZY VILLAGE

Excellent exposures of the Black River are shown at two of the quarries in Chazy village, Clinton county, New York, and in the bed of the Chazy river. The lowest beds following the strata of the upper Chazy are of a dove-colored barren limestone, perhaps belonging to the Birdseye, followed by the distinctive Black River strata which here have a thickness of 34 feet. It is doubtful whether these beds extend into those of the Trenton proper. Characteristic Black River fossils occur throughout.

ISLE LA MOTTE

Several sections of the Black River and of the Trenton are shown on isle la Motte, but none of them are continuous. On the eastern side of the island an excellent example is afforded of the Utica shales faulted sharply down against the Trenton.

HIGHGATE SPRINGS

The Highgate Springs section is in the form of a steep north and south anticline, which at its southern end is curved sharply to the westward. The crest of this anticline has then suffered erosion, so that the whole series of faunas from the Chazy to the Utica is shown in consecutive thin bands, extending east and west on each side of the crest. It was this condition of affairs that gave to Professor Marcou the idea of the development of colonies or lenticles containing precursory faunas at this place.*

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*J. Marcou: Bull. Soc. Geol. France, part iii, vol. ix, 1881, pp. 14, 15.

As this is the most northerly locality of the Trenton which we have so far observed within the Champlain valley, it is interesting to note that several of the same zones found in the extreme southern section at Larrabee point persist, although the apparent thickness of the layers is a great deal less than at points farther south, perhaps largely in consequence of squeezing and forcing of the layers out of their true position, as the result of the crumpling of the anticline.

On the opposite side of the lake at Rouse point, at Point-au-Fer, and on Alberg peninsula, the Utica formation occurs, in various outcrops, but containing few fossils.

Range of particular Faunas and Species

The Black River formation is characterized in the region, in its lower portion, by a zone composed almost exclusively of *Leperditia fabulites*, best shown on Button island, but also seen elsewhere.

The next well marked zone is that of *Stromatocerium rugosum*, *Columnaria alveolata*, *Tetradium fibratum*, and *Rhynchotrema inæquivalve*, which extends through over 60 feet of the top of the Black River, and with which fossils are associated *Strophomena billingsi* and *S. incurvata*, *Zygospira recurvirostris*, and *Z. exigua*, *Zaphrentis canadensis*, *Schizocrinus nodosus*, *Bumastus trentonensis*, and *Thaleops*, probably *ovata*.

Near the top of the Black River, in a zone particularly well marked at Chazy, New York, is a large species of *Maclurea*, which both in stratigraphic position and in specific characters is distinct from *Maclurea magna* of the Chazy, which occurs so abundantly in the neighborhood. It is a large species, more rounded than *M. magna*, and marked with concentric grooves around the periphery, and is probably identical with *M. logani* of Canada. Its associates are *Stromatocerium rugosum*, *Rafinesquina alternata*, *Rhynchotrema inæquivalve*, *Dalmanella testudinaria*, *Hormatoma gracilis*, *Lophospira bicincta*, *Lingula elongata*, *Calymmene senaria*, *Ceraurus pleurexanthemus*, etcetera.

Dalmanella testudinaria, *Rafinesquina alternata*, *Plectambonites sericeus*, *Protowarthia cancellata*, *Calymmene senaria*, *Ceraurus pleurexanthemus*, and *Trinucleus concentricus* are found universally through all the beds of lake Champlain valley.

Doctor Sardeson has recently attempted* to correlate by the employment of specific or varietal names the forms of *Plectambonites sericeus* and *Dalmanella testudinaria* of Minnesota, and a suite of the representatives of those species from our localities was sent him. He determines among them the varieties *P. sericeus aspera* James, a form related to *P. minnesotensis* Sardeson, *P. recedens* Sardeson, and *Dalmanella testudinaria meeki* Miller, *D. emacerata* Hall, a form related to *D. porrecta* Sardeson and *D. subæquata* var. *gibbosos* of Billings. A tabulation of the occurrences of these forms, as identified in the lake Champlain valley, does not indicate any rule of variation of one to another, but all appear to be irregularly distributed through the series, the variation being due more to changes in the character of the deposits and life conditions in particular beds than to any progressive order of evolution to established fixed types.

A short distance above the top of the Black River occurs a zone which may be traced the whole length of the lake by its abundance of *Parastrophia hemiplicata*. This fossil occurs scatteringly higher in the series, but is nowhere else abundant, and it appears in force without precursors below. The younger specimens very

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* F. W. Sardeson: American Geologist, vol. xix, 1897, pp. 91–111 and 180–190.

often resemble those of *Triplesia extans*, a fossil which is frequent in a corresponding position above layers containing *Parastrophia hemiplicata* in central New York,* but which has not been found in the lake Champlain valley. Associated in the *Parastrophia hemiplicata* bed is what appears to be an undescribed variety of *Dalmanella*, of large size and marked by very strong plications. Still another new form of *Dalmanella* occurs higher in the series, and also a species which is perhaps identical with *Dalmanella delicatula* of Billings.

Murchisonia bellicincta appears in the tabulation prevailingly in the lower Trenton, associated with *Protowarthia cancellata*, *Liospira americana*, *Subulites elongatus*, *Bellerephon capex*, *Whitella ventricosa*, *Ctenodonta levata*, and *C. dubia*, *Dinorthis pectinella*, *Hormotoma gracilis*, and numerous trilobites, such as *Illænus americanus*, *Ceraurus pleurexanthemus*, *Bathyurus* sp., etcetera.

By coincidence two species laid aside as new in the preliminary field study very shortly afterward appeared in volume iii of the Paleontology of Minnesota. These are *Pterygometopus eboraceus* of Clarke, described from Rawlins Mills, New York, and found on lake Champlain, at Larrabee point at about 90 feet and on Crown point at about 80 feet above the base of the respective sections. Another *Pterygometopus*, probably *intermedius*, also occurs in neighboring layers. The other newly recognized species is *Schizambon dodgei*, which Winchell and Schuchert describe from the dark, compact limestone near the top of the Trenton, at Sandy Hill, New York, and which occurs, lower in the series, at Larrabee point.

The most notable fossil assemblage in the upper portion of the section is that of *Lingula vanhorni*, and *L. æqualis*, *Orbiculoidea lamellosa*, *Trematis terminalis*, various graptolites (seldom well preserved), *Leptobolus insignis*, *Ctenodonta dubia*, *Conularia trentonensis*, and *Holopea paludiniformis*.

The shaly masses toward the top of the Trenton abound in masses of *Monticuliporidæ*.

The most interesting fauna of all, however, is that of the very high Trenton or Utica of Cumberland head, which establishes a connection between the faunas of New York and Canada. Here we find associated *Leptobolus insignis*, *Lingula æqualis*, *L. curta* and *L. riciniformis* of the New York Trenton, with *L. cobourgensis* and *L. progne* (at Crown point), both being Canadian species of Billings, together with a new species, resembling *L. whitfieldi* of Ulrich. *Zygospira exigua* and *Z. recurvirostris*, *Trematis terminalis*, *Schizocrania filosa*, *Rafinesquina alternata*, *Ctenodonta gibbosa* and *C. levata*, *Calymmene senaria*, *Isotelus gigas*, *Ceraurus pleurexanthemus*, *Trinucleus concentricus*, and *Odontopleura parvula*, all of which are New York, and most of them also Illinois and Minnesota forms, are associated with *Trematis ottawensis*, *Illænus americanus*, and *Turrilepis canadensis*, all of Canada, the latter previously reported from the lower Utica formation, near Ottawa, with many of the same associates.† The lower portion of the series, which is so largely developed on Cumberland head, contains in all localities a fauna of numerous very small individuals of *Ceraurus pleurexanthemus* and *Triarthrus becki*, the latter, on account of their small size, resembling *T. fisheri* of Billings, but which do not show the series of minute but distinct pits along the front margin of the cephalon which occur in that species. Hall ‡ notes *Phacops callicephalus* and *Ceraurus pleurexanthemus* in Wisconsin occur-

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* T. G. White: Ann. Rept. Director New York State Mus., 1899, Appendix A, pr. 28.

† H. Woodward: Geol. Magazine, pl. iii, vol. vi, 1889, pp. 271–275; and H. M. Ami: Ibid., October, 1888.

‡ J. Hall: Foster and Whitney's Rept., vol. ii, 1851, p. 212.

ring, as the two trilobites mentioned do on lake Champlain, in association with crinoidal columns of unusually large size, while the trilobites are unusually small. He considers that the admixture of arenaceous matter, while it did not interfere with the production of the species, has diminished their size.

CONCLUSIONS

Messrs Matthew* and Ruedemann† have traced the Utica as a cold current from Europe invading the warm seas of the Trenton, and passing from the northeast around the southern slopes of the Adirondack island. There seems to be evidence pointing to the conclusion that the currents depositing limestone in the clear seas of the earlier period studied in this paper were from southwest to northeast, and that the currents gradually changed to a reverse direction over the soft muds which closed the period. Some of this evidence is found in the thinning of the Birdseye formation in the Champlain valley; in the luxuriant development of warm water corals and delicate bryozoa; in the developmental forms of the species common to the central New York and Champlain Trenton on the one hand and the Champlain and Canadian Trenton on the other.

The Black River zones are well marked and characteristic, and differ considerably from those of the western New York sections. The group is about 75 feet thick in the southern portion of the region.

The Trenton carries a very abundant fauna, the species not so strikingly limited to zones as in the adjacent groups, but commingling New York and Canadian types. Its thickness in the region is from 150 to 200 feet.

The Utica presents at least 475 feet in thickness of shales, carrying a "stunted" fauna for the most part, but a great variety of linguloid forms. No fossils characteristic of any higher formations are found in the region.

The localities afford a rich paleontological field of investigation and have furnished us to date 42 species of brachiopods, 14 of lamellibranchs, 23 of gastropods, 9 of cephalopods, and 16 of trilobites.

Remarks on the paper of Mr White were made by Henry M. Seely, H. P. Cushing, H. M. Ami, C. S. Prosser, the chairman, and the author.

DISCUSSION

Dr H. M. Ami pointed out the excellent detailed stratigraphical as well as paleontological work for the lake Champlain valley. Many of the faunal zones and other peculiarities in the stratigraphical column, as pointed out by Doctor White, were identical with their Canadian equivalents. The beds holding *Leperditia fabulites* band, overlaid by the *Columnaria halli*, and these in turn capped by a *Maclurea* limestone, constituting the various members of the Birdseye and Black River formations in the Ottawa Paleozoic basin, agree well, as far as faunal succession and relation and also as regards their origin and lithological characters.

As regards the Trenton limestone, while the leading forms of fossil organic remains were identical, both in the Champlain valley and Ontario, there were a number of interesting points of difference in the vertical range and position assigned to certain species, as, for example, *Trematis ottawaensis*. This species is in-

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*G. F. Matthew: Bull. Nat. Hist. Soc. New Brunswick, vol. xi, 1893, pp. 3–18.

†R. Ruedemann: American Geologist, vol. xix, 1897, pp. 367–391.

variably characteristic of Lower Trenton in the Ottawa valley near Ottawa, and *Zygospira recurvirostra* was found abundantly in the uppermost beds of this formation. So also in the case of *Ceraruus plurexanthemus*, this trilobite occupies the basal beds of the Utica, at Ottawa; but occurs low down in the Trenton of the lake Champlain district.

The lacuna existing at the interval of transition from the Trenton to the Utica terranes along lake Champlain is unfortunate, as everywhere in the Ottawa and Saint Lawrence valleys, in Canada and in Ontario east of Toronto, these two formations pass imperceptibly one into the other. Along the Rideau river, at Ottawa, at Rochesterville, and in numerous other localities in the vicinity of Ottawa, the pyroschists of the Utica or bituminous shale follow directly upon the Trenton without any discordance of stratification whatever. The enormous thickness assigned to the Utica, of upward of 500 feet, was surprising, for the whole of the Utica formation at Ottawa is scarcely more than 75 feet in thickness.

In the absence of the authors, the next two papers were read by title.

STRATIGRAPHY OF THE POTTSVILLE SERIES IN KENTUCKY

BY MARIUS R. CAMPBELL

AMERICAN HOMOTAXIAL EQUIVALENTS OF THE ORIGINAL PERMIAN

BY CHARLES R. KEYES

The following paper was then read:

THE NEWARK SYSTEM IN NEW YORK AND NEW JERSEY

BY HENRY B. KÜMMEL

Remarks were made by the chairman, by N. S. Shaler, I. C. Russell, J. E. Wolff, A. Heilprin, J. B. Woodworth, and the author. The paper is published in the Journal of Geography, volume vii, 1899, pages 23–52.

The two following papers were read and, without discussion, closed the afternoon session:

JURASSIC FORMATIONS OF THE BLACK HILLS OF SOUTH DAKOTA

BY N. H. DARTON

This paper is printed as pages 383–396 of this volume, with description and illustrations of the fossils by Dr Charles R. Eastman, which also appears as pages 397–408 under the title "Jurassic Fishes from Black Hills of South Dakota."

MESOZOIC STRATIGRAPHY IN SOUTHEASTERN BLACK HILLS

BY N. H. DARTON

The Society adjourned. No evening session was held, the Fellows being invited to a reception tendered the several societies meeting at the same time in the city at the American Museum of Natural History, with an address by Professor H. F. Osborn.

SESSION OF THURSDAY, DECEMBER 29

The Society was called to order at 10 o'clock a m, President Stevenson in the chair.

Dr J. C. Smock reported that the Auditing Committee had found the accounts of the Treasurer correct, and the Society adopted the report.

The report of the Council was taken from the table and adopted without debate.

Following is the report of the Photograph Committee: *

NINTH ANNUAL REPORT OF COMMITTEE ON PHOTOGRAPHS

The committee report the addition of 320 views, bringing the full number in the collection up to 1,878. The donors are as below:

(1) Second Geological Survey of Pennsylvania	144
(2) U. S. Geological Survey	106
(3) U. S. National Museum (George P. Merrill)	1
(4) Professor J. F. Kemp	7
(5) Geological Survey of Iowa	58
(6) Mr T. C. Hopkins	4

The 144 views presented by the Second Geological Survey are prints made from selected negatives of the entire series presented, as noted in the Eighth Annual Report of your committee.

The committee asks a continuation of the appropriation of the sum of $15 for expenses during 1899.

Respectfully submitted. GEORGE P. MERRILL,
Chairman.

WASHINGTON, *December*, 1898

REGISTER OF PHOTOGRAPHS RECEIVED IN 1898

One hundred and forty-four (144) views (with negatives) presented by Mr E. V. D'Invilliers for the Second Geological Survey of Pennsylvania

Size, 5 by 7 inches. For prints, address Chairman Committee on Photographs

1559. *Pseudopecopteris macilenta* (L. and H.) Lx. Upper Pottsville series. Washington county, Arkansas. *Lepidocystis* (Polysporia) *salisburyi* Lx. Pottsville series. Days gap, Alabama.

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* By a misunderstanding or inadvertence it was supposed that this report had not been received, and consequently it was not presented to the meeting. It was presented at the Washington meeting December 28, 1899, and adopted, and is here printed in its proper place.

1560. *Sphenopteris* (Hymenophyllites) *pendulata* Lx. MSS. (Fertile.) *Lepidophyllum alabamense* D. W. MSS. Pottsville series. Cordova, Alabama.

1561. *Pseudopecopteris obtusiloba* (Stb.) Lx., var. *dilatata* Lx. MSS. Kanawha series. West Virginia.

1562. *Pseudopecopteris obtusiloba* (Stb.) Lx. Kanawha series. West Virginia.

1563. *Dictyopteris sub-brongniartii* Gr. Ey. Coal Measures (Westphalien). France.

1564. Spirophyton. A probable Pseudophyte. Lower Carboniferous. Near Warren, Pennsylvania.

1565. *Asterophyllites gracilis* Lx. Fruiting spikes. Pottsville series. Dade county, Georgia.

1566. *Arthrophycus harlani* (Conr.) Hall. Medina sandstone. Locality unknown.

1567. *Arthrophycus harlani* (Conr.) Hall. Probably from Medina sandstone. Locality unknown.

1568. *Callipteridium tracyanum* Lx. Upper Pottsville (Walden SS). Tracy City, Tennessee.

1569. *Neuropteris clarksoni* Lx. High anthracite coal ("G"). Olyphant, Pennsylvania. (Photograph reduced.)

1570. Pseudophyte. Casts of trails of molluscs. Formation and locality unknown.

1571. *Eurypterus mansfieldi*, Hall. Figured in Second Geological Survey of Pennsylvania, page 3, plate 5, figure 3. Specimen from just below Darlington cannel coal, near Cannelton, Darlington county, Pennsylvania.

1572. Natural casts of Atrypa, Spinosa, Spirifer, Rhynchonella, Pelicypods, and Tantaculites. Horizon, Hamilton. A splendid illustration of associated Hamilton species.

1573. Natural sections of spire-bearing Brachiopods; also a few Tentaculites preserved. Horizon probably Lower Helderberg.

1574. Stripping at Hollywood colliery No. 1, looking east. Report A. C., Second Geological Survey of Pennsylvania, page plate No. 52.

1575. Stripping at Hollywood colliery No. 1, looking east. Report A. C., Second Geological Survey of Pennsylvania, page plate No. 51.

1576. Stripping at Hollywood colliery No. 1, looking east. Report A. C., Second Geological Survey of Pennsylvania, page plate No. 51.

1577. Stripping at Hollywood colliery No. 1, looking east. Report A. C., Second Geological Survey of Pennsylvania, page plate No. 51.

1578. Workings at Hollywood colliery, looking east. Report A. C., Second Geological Survey of Pennsylvania, page plate No. 12.

1579. Workings at Hollywood colliery No. 1, looking south. Report A. C., Second Geological Survey of Pennsylvania, page plate No. 53.

1580. Pottsville deep shaft. Report A. C., Second Geological Survey of Pennsylvania, page plate No. 33.

1581. Breaker in process of construction, Kohinoor colliery. Report A. C., Second Geological Survey of Pennsylvania, page plate No. 45.

1582. Culm and rock heaps at Shenandoah. Report A. C., Second Geological Survey of Pennsylvania, page plate No. 49.

1583. Kohinoor Colliery culm and rock dump. Report A. C., Second Geological Survey of Pennsylvania, page plate No. 50.

1584. No. 215. Anderson's tipple, Venetia, N. W.

1585. Black Diamond tipple. Report K 4, Second Geological Survey of Pennsylvania, plate iv.

1586. Gilmore's Slide tipple. Report K 4, Second Geological Survey of Pennsylvania, plate iii.
1587. Snow Hill tipple. Report K 4, Second Geological Survey of Pennsylvania, plate ii.
1588. Caledonia tipple. Report K 4, Second Geological Survey of Pennsylvania, plate i.
1589. Cornell and Werling Mine tipple, Youghiogheny river. Report K 4, Second Geological Survey of Pennsylvania, plate xii.
1590. Venetia Mine tipple, Peters creek. Report K 4, Second Geological Survey of Pennsylvania, plate xi.
1591. Little Saw-mill Run Railroad Company's tipple, South Pittsburgh. Report K 4, Second Geological Survey of Pennsylvania, plate x.
1592. Amity Mine tipple. Report K 4, Second Geological Survey of Pennsylvania, plate ix.
1593. Horner and Roberts' tipple. Report K 4, Second Geological Survey of Pennsylvania, plate viii.
1594. Walton's upper tipple. Report K 4, Second Geological Survey of Pennsylvania, plate vii.
1595. New Coal Bluff tipple. Report K 4, Second Geological Survey of Pennsylvania.
1596. Relief map of the rocky ridge and east broad top coal basins, in Huntington county, Pennsylvania. By Edward B. Harden.
1597. Relief map of Bald Eagle mountain and Nittany valley. By Edward B. Harden.
1598. Model of the Cornwall iron ore mines, looking north. Annual Report of Geological Survey of Pennsylvania, 1885.
1599. Compressed air locomotive, Old Eagle mine. Report K 4, Second Geological Survey of Pennsylvania, plate v.
1600. Avondale quarry, Delaware county, Pennsylvania.
1601. Deshong's quarry, near Chester, Pennsylvania.
1602. Ward's quarry, near Chester, Pennsylvania.
1603. Ward's quarry, near Chester, Pennsylvania.
1604. Figure 5, Ohlinger Dam quarry, showing both dip and cleavage in Laurentian gneiss, 3 miles northeast of Reading, Pennsylvania. Report D 3, volume 2, Second Geological Survey of Pennsylvania.
1605. Leiper quarry, Delaware county, Pennsylvania.
1606. Face of Deshong's quarry, near Chester, Pennsylvania.
1607. Leiper quarry, Delaware county, Pennsylvania.
1608. No. 156. Rocks exposed in railroad cut, Schuylkill Valley railroad, one-half mile above Lafayette station, P. and R. railroad.
1609. No. 155 (page 116). Old Quarry No. 2, at Slatington, Lehigh county, Pennsylvania, looking west. Report D 3, volume 1, Second Geological Survey of Pennsylvania, 1882, plate 1.
1610. No. 159 (page 117). American slate quarry No. 1, Slatington, Pennsylvania, looking southwest. Report D 3, volume 1, Second Geological Survey of Pennsylvania, 1883, plate 2.
1611. No. 159 (page 117). American quarry No. 2, at Slatington, Lehigh county, Pennsylvania. Report D 3, volume 1, Second Geological Survey of Pennsylvania, 1883, plate 3.

1612. Trap on the south side of the Cornwall big hill, where the spiral railroad enters the upper workings. Annual Report of Geological Survey of Pennsylvania, 1885.

1613. Feldspar quarry, Brandywine Summit kaolin works, Delaware county, looking north 20 degrees east, plate xxiii.

1614. American kaolin works, New Garden township, Chester county, looking north 5 degrees east. Report C 5, Second Geological Survey of Pennsylvania, plate xxvii.

1615. Kaolin mine at Hockessin, Delaware, looking north 60 degrees east. Report C 5, Second Geological Survey of Pennsylvania, plate xxviii.

1616. Figure 7, Potsdam sandstone of Neversink hills, exposed in the railway cut 3½ miles below Reading, Berks county, Pennsylvania, looking north. Report D 3, volume 2, Second Geological Survey of Pennsylvania, plate 3.

1617. Figure 6, Potsdam sandstone of Neversink hills, exposed in the railway cut at the Lover's Leap, 3 miles south of Reading, Berks connty, Pennsylvania, looking south 45 degrees east. Report D 3, volume 2, Second Geological Survey of Pennsylvania.

1618. Contorted gneiss. Sckuylkill river, ¾ mile above Lafayette station, Schuylkill Valley railroad. No. 158.

1619. Duplicate of 1686.

1620. Kettle holes in the moraine in Cherry valley, Monroe county, Pennsylvania, looking north-northeast. Report Z, Second Geological Survey of Pennsylvania, plate vii.

1621. The terminal moraine crossing Cherry valley, Monroe county, Pennsylvania, looking southwest. Report Z, Second Geological Survey of Pennsylvania, plate viii.

1622. Long ridge, the terminal moraine on the Pocono plateau, 2,000 feet above tide. Monroe county, looking north-northeast. Report Z, Second Geological Survey of Pennsylvania, plate ix.

1623. Moraine kettle and kames in Cherry valley, Monroe county, Pennsylvania. Report Z, Second Geological Survey of Pennsylvania, plate x.

1624. Kames in Cherry valley, Monroe county, Pennsylvania. Report Z, Second Geological Survey of Pennsylvania, plate xi.

1625. Glacial scratches on Clinton red shale (No. 5), near Fox gap, Monroe county, Pennsylvania, plate xii.

1626. Great glacial grove on table rock, at the Delaware water gap. Report Z, Second Geological Survey of Pennsylvania, plate xv.

1627. The terminal moraine west of Coles creek, in Columbia county. Report Z, Second Geological Survey of Pennsylvania, plate xviii.

1628. Glacial till exposed at the Bangor slate quarry at Bangor, Northampton county. Report Z, Second Geological Survey of Pennsylvania, plate iv.

1629. A glaciated boulder at the Bangor slate quarry at Bangor, in Northampton county, Pennsylvania. Report Z, Second Geological Survey of Pennsylvania, plate v.

1630. Terminal moraine near Saylorsburg, Monroe county, Pennsylvania, looking north-northwest. Report Z, Second Geological Survey of Pennsylvania, plate vi.

1631. Boulder of Pottsville conglomerate on the crest of Penobscot mountain, Luzerne county, Pennsylvania, looking west. Report Z, Second Geological Survey of Pennsylvania, plate xvi.

1632. The terminal moraine crossing Fishing Creek valley, Columbia county, Pennsylvania, looking southwest. Report Z, Second Geological Survey of Pennsylvania, plate xvii.
1633. The Bryn Mawr gravel at Crawford's fireclay pit, Delaware county, looking north 34 degrees west. Report C 5, Second Geological Survey of Pennsylvania, plate xxii.
1634. Glacial striæ on the southern slope of Godfrey's ridge, in Monroe county, Pennsylvania. Report Z, Second Geological Survey of Pennsylvania, plate xiii.
1635. Front side of terminal moraine near Bangor, Northampton county, looking southeast. Report Z, Second Geological Survey of Pennsylvania, plate i.
1636. Inside view of terminal moraine near Bangor, Northampton county, looking northwest. Report Z, Second Geological Survey of Pennsylvania, plate 2.
1637. Moraine hummocks west of Bangor, Northampton county, looking southwest. Report Z, Second Geological Survey of Pennsylvania, plate 3.
1638 to 1643, inclusive. Castle rock, Edgemont township, Delaware county, Pennsylvania.
1644. Castle rock, eastern end, Edgemont township, looking north 80 degrees east. Report C 5, Second Geological Survey of Pennsylvania, plate xxiii.
1645. Castle rock, western end, Edgemont township, looking north 15 degrees east. Report C 5, Second Geological Survey of Pennsylvania, plate xxxii.
1646. Castle rock, Edgemont township, Delaware county, Pennsylvania, looking south 55 degrees east. Report C 5, Second Geological Survey of Pennsylvania, plate xxx.
1647. Limestone quarry, Port Kennedy, Pennsylvania. Phœnix Iron Company.
1648. Trap rocks at Gulf Mills, Pennsylvania.
1649. Lafayette soapstone quarry, Montgomery county, Pennsylvania.
1650. Lafayette soapstone quarry, Montgomery county, Pennsylvania.
1651. Trap rocks at Gulf Mills, Pennsylvania.
1652. Trap boulders, French Creek falls, Pennsylvania.
1653. Trap boulders, French Creek falls, Pennsylvania.
1654. Trap boulders, French Creek falls, Pennsylvania.
1655. Water Sheet narrows, Huntingdon county, Pennsylvania. Juniata river.
1656. Breaker at Hollywood colliery, showing stripping.
1657. Synclinal in mammoth bed, Hollywood colliery, Hazelton, Pennsylvania. Shows open-work mining after stripping.
1658. Synclinal in mammoth bed, Hollywood colliery, Hazelton, Pennsylvania. Shows open-work mining after stripping.
1659. Boring for oil. Sadsbury township, Chester county, Pennsylvania.
1660. Kennedy's syenite quarry, near Wayne.
1661. Gneiss peak on Harvey Thomas farm, L. Bethel township, Delaware county, Pennsylvania.
1662. Burned rocks, Fayette city, Monongahela river.
1663. Rausch's gravel quarry, Bethlehem, Pennsylvania.
1664. Limestone quarry, Bethlehem, Pennsylvania.
1665. Old Wheatley lead mine, near Phœnixville, Pennsylvania.
1666. Old Smelting Works mine, near Phœnixville, Pennsylvania.
1667. Old Wheatley lead mine, near Phœnixville, Pennsylvania.
1668. Pottsville from Sharp mountain.

1669. Head frame, Kaska William colliery, Schuylkill county, Pennsylvania.
1670. R. D. Lacoe's museum, Pittston, Pennsylvania. (R. D. L. and George B. Simpson.)
1671. Culm bank, Turkey Run colliery, Schuylkill county, Pennsylvania.
1672. Gap at Cumberland, Maryland.
1673. Gap at Cumberland, Maryland.
1674. Lower Helderberg limestone, near Mount Savage Junction, Maryland.
1675. Lower Helderberg limestone, near Mount Savage Junction, Maryland.
1676. Old marble quarry, Marble Hall, Montgomery county, Pennsylvania.
1677. Cut on Philadelphia and Reading railroad, near Reading, Potsdam quartzite (Neversink mountain).
1678. Cut through limestone, Schuylkill Valley railroad, below Norristown.
1679. Cut through limestone, Schuylkill Valley railroad, below Norristown.
1680. Delaware water gap.
1681. Avondale quarry, Delaware county, Pennsylvania.
1682. Avondale quarry, Delaware county, Pennsylvania.
1683. Contorted gneiss, Spring Mill, Montgomery county.
1684. Contorted gneiss, Spring Mill, Montgomery county.
1685. Anticlinal on Schuylkill river 2 miles above Port Clinton.
1686. Cut on Schuylkill Valley railroad showing "creep."
1687. Potts' limestone quarry, below Norristown.
1688. Syenitic gneiss near Spring Mill.
1689. Potts' limestone quarry, looking south 70 degrees west.
1690. Potts' limestone quarry, looking south 70 degrees west.
1691. Limestone in cuts on Schuylkill Valley railroad below Norristown.
1692. Limestone in cuts on Schuylkill Valley railroad below Norristown.
1693. Limestone quarry, Port Kennedy, Phœnix Iron Company.
1694. Old serpentine quarry near Devon, Montgomery county, Pennsylvania.
1695. Quartz vein in cut at Lafayette station, Montgomery county, Pennsylvania.
1696. Vein in Cornwall iron ore mine.
1697. Limestone in Schuylkill Valley railroad cut, near Mogeetown, Pennsylvania.
1698. Lower Avondale quarry, Nether Providence township, Delaware county, Pennsylvania. View taken looking south-southwest. Report C 5, plate viii, Geological Survey of Pennsylvania.
1699. Contorted gneiss of Wissahickon creek, near the Philadelphia and Reading railroad bridge. Report C 4, plate viii, Geological Survey of Pennsylvania.
1700. Creep striæ on roofing slate, Bangor, Northampton county, Pennsylvania. Report Z, plate 61, Geological Survey of Pennsylvania.
1701. Creep striæ on roofing slate, Bangor, Northampton county, Pennsylvania. Report Z, plate 61, Geological Survey of Pennsylvania.
1702. Glaciated boulder from moraine, base of Huntingdon mountain, near Jonestown, Columbia county, Pennsylvania. Report Z, plate 118, Geological Survey of Pennsylvania.

One hundred and six (106) views presented by the United States Geological Survey

Size, 5 by 7 inches. Thirty-one photographed by C. D. Walcott

1703. Missouri River beds, above railroad bridge, near Townsend, Montana. (523.) C. D. W., 1898.

1704. Hogback, formed by upturned basal Cambrian sandstone (Flathead), Indian creek, 4 miles west of Townsend, Montana. (525.) C. D. W., 1898,

1705. Hogback, formed by upturned basal Cambrian sandstone (Flathead), Indian creek, 4 miles west of Townsend, Montana. (525*a*.) C. D. W., 1898.

1706. Panoramic view of Paleozoic rocks at mouth of Indian creek, 4 to 6 miles west of Townsend, Montana. (526*a*.) C. D. W., 1898.

1707. Panoramic view of Paleozoic rocks at mouth of Indian creek, 4 to 6 miles west of Townsend, Montana. (526*b*.) C. D. W., 1898.

1708. Slaty shales in which pre-Cambrian fossils were found; mouth of Deep Creek canyon, 16 miles east of Townsend, Montana. (527*b*.) C. D. W., 1898.

1709. Paleozoic rocks near mouth of Avalanche canyon, west foot of Big Belt mountains, Montana, 12 miles east of Canyon Ferry. (529.) C. D. W., 1898.

1710. Eroded Carboniferous sandstones, in cliff 8 miles south of Livingston, Montana, west side of Yellowstone river. (534.) C. D. W., 1898.

1711. Eroded Carboniferous sandstones, in cliff 8 miles south of Livingston, Montana, west of Yellowstone river. (534*a*.) C. D. W., 1898.

1712. Eroded Carboniferous sandstones, in cliff 8 miles south of Livingston, Montana, west side of Yellowstone river. (534*b*.) C. D. W., 1898.

1713. Eroded Carboniferous sandstones, in cliff 8 miles south of Livingston, Montana, west side of Yellowstone river. (534*c*.) C. D. W., 1898.

1714. Eroded Carboniferous sandstones, in cliff 8 miles south of Livingston, Montana, west side of Yellowstone river. (535*c*.) C. D. W., 1898.

1715. View looking north from Point of Rocks down Yellowstone valley, about 34 miles south of Livingston, Montana. (539.) C. D. W., 1898.

1716. View of Carboniferous strata on north side of Beaver creek, above Missouri river, Big Belt mountains, Montana. (537.) C. D. W., 1898.

1717. Waterfall over Cambrian limestones, Sheep creek, toward summit of Teton range, southwest of Jackson lake, Wyoming. (541.) C. D. W., 1898.

1718. Big mud geyser shortly after eruption, Yellowstone National park. (545.) C. D. W., 1898.

1719. Brink of Upper falls of the Yellowstone, Yellowstone National park. (547.) C. D. W., 1898.

1720. Mouth of Fountain geyser shortly before eruption, Yellowstone National park. C. D. W., 1898.

1721. Siliceous deposits in the basin of the Great Fountain geyser, Yellowstone National park. (549.) C. D. W., 1898.

1722. Terrace pools on lower slopes of Angel terrace, Yellowstone National park. (550.) C. D. W., 1898.

1723. Calcareous points covering bottom of pool, Angel terrace, Mammoth hot springs, Yellowstone National park. (552.) C. D. W., 1898.

1724. Calcareous deposits in pool, summit of Angel terrace, Mammoth hot springs, Yellowstone National park. (553.) C. D. W., 1898.

1725. Calcareous (mushroom-like) concretionary deposits, Angel terrace, Mammoth hot springs, Yellowstone National park. (554.) C. D. W., 1898.

1726. Calcareous (mushroom-like) concretionary deposits, Angel terrace, Mammoth hot springs, Yellowstone National park. (554*a*.) C. D. W., 1898.

1727. Calcareous algæ in outlet of pools, summit of Angel terrace, Mammoth hot springs, Yellowstone National park. (555.) C. D. W., 1898.

1728. "Ox-bow" bend, Trout creek, Hayden valley, Yellowstone National park. (556.) C. D. W., 1898.

1729. North end of Teton range, northwest of Jackson lake, Wyoming. (557.) C. D. W., 1898.

1730. View of the Teton range from the east shore of Jackson lake, Wyoming. (558*a*.) C. D. W., 1898.

1731. Basal Cambrian sandstones of section at mouth of Two-mile canyon, 2 miles south of Malad City, Idaho. (562*a*.) C. D. W., 1898.

1732. Summit of ridge. View from the north, about 3 miles south of Malad City, Idaho. (563.) C. D. W., 1898.

1733. Boulders in Firehole river, Yellowstone National park. (565*a*.) C. D. W., 1898.

Size, 6 by 7½ inches. Nine photographed by H. W. Turner

1734. Crescent lake, in the Yosemite National park. The morainal dam which has formed the lake is shown, the outlet being in the middle, where the driftwood has accumulated. H. W. T.

1735. View from near Sentinel Dome, in the Yosemite National park, showing the canyon of Tenaya creek and the roches-moutonnees-like surface of the plateau north of Yosemite valley. H. W. T.

1736. Rock basin in biotite-granite. Ridge south of Morrison creek, in the Yosemite National park. The diameter of the basin is about 1 meter and its depth about 15 centimeters. These little basins are formed by atmospheric agency without aid of running water. H. W. T.

1737. Showing the weathering of biotite-granite on ridge south of Morrison creek, a branch of the Tuolumne river, in the Yosemite National park. On the boulder to the left may be seen several little rock basins which by growth have coalesced. H. W. T.

1738. Exfoliating granite east of Royal Arch lake, which drains into the South Merced river, in the Yosemite National park. H. W. T.

1739. Exfoliating granite on slope northwest of Grouse lake, in the Yosemite National park. The different steps formed by the layers are all glaciated, showing that the exfoliation took place before the final retreat of the ice. H. W. T.

1740. Exfoliating granite on slope northwest of Grouse lake, in the Yosemite National park. The large boulders in the foreground are polished on their upper surface and have been fractured and moved by frost and heat into their present position since the retreat of the ice. H. W. T.

1741. Boulder of an igneous pudding-stone on ridge north of Yosemite valley. It is composed of nodules of diorite cemented by biotite-granite. The measure is 25 centimeters long. H. W. T.

1742. Granite striated and polished by the ice, near Johnson lake, in the Yosemite National park. H. W. T.

Size, 4½ by 6½ inches. Thirty-seven photographed by G. K. Gilbert

1743. Shore of lake Ontario, Niagara county, New York. Illustrates mode of origin of beach shingle by showing rock in place and angular rocks recently detached. Gilbert, 1898.
1744. Beach of flat shingle. Shore of lake Ontario at Golden Hill creek, New York. Gilbert, 1898.
1745. Beach of well rounded shingle. Shore of lake Ontario at Golden Hill creek, New York. Gilbert, 1898.
1746. Cemented shingle in spit of glacial lake Iroquois at Lewiston, New York. Gilbert, 1898.
1747. Section of spit of glacial lake Iroquois at Lewiston, New York. The dip is landward, indicating growth on the inside of the spit. Gilbert, 1898.
1748. Section of spit of glacial lake Iroquois at Lewiston, New York. The dip is landward, indicating growth on the inside of the spit. Gilbert, 1898.
1749. Cut terrace of the Iroquois shore line, 2 miles west of Dickersonville, New York. Lacustrine plain, bed of lake Iroquois, near Jeddo, New York. The water edge was at base of cliff. The cliff is carved from Medina shale. Gilbert, 1898.
1750. Till plain, ½ mile south of Jeddo, Niagara county, New York. Gilbert, 1898.
1751. Cross-bedding and unconformity in sand kame, 3 miles east of Lockport, New York. Gilbert, 1898.
1752. Till. Shore of lake Ontario, Wilson, New York. Gilbert, 1898.
1753. Deposit by torrent of Erian water on the withdrawal of the ice-sheet from the escarpment at Lewiston, New York. Unassorted and unworn alluvium. Gilbert, 1898.
1754. Section of talus, Niagara gorge. Gilbert, 1898.
1755. Angular gravel in kame, south of Royalton, Niagara county, New York. Gilbert, 1898.
1756. Solitary gravel kame, 3 miles south of Middleport, New York. Gilbert, 1898.
1757. Escarpment of the Niagara limestone, looking west from a point on the talus near Lewiston, New York. Gilbert, 1898.
1758. Niagara escarpment capped by Niagara limestone, looking east from a point 5 miles west of Lockport, New York. Gilbert, 1898.
1759. Niagara escarpment without capping of Niagara limestone; looking west from a point near Middleport, New York. Gilbert, 1898.
1760. Drowned valley of Twelve-mile creek, near Wilson, Niagara county, New York. Water lilies grow on submerged alluvial plain. Gilbert, 1898.
1761. Head of estuary of Twelve-mile creek, Niagara county, New York. Submerged alluvial plain supports rushes. Gilbert, 1898.
1762. Estuary of Eighteen-mile creek, near Olcott, Niagara county, New York. Channel deep, current slow. Submerged alluvial plain supports rushes. Gilbert, 1898.
1763. Valley of Eighteen-mile creek, Niagara county, New York, above head of estuary. Channel shallow, current rapid; alluvial plain dry except during flood. Gilbert, 1898.

1764. Post-glacial anticline, Hopkins creek, Niagara county, New York. The displacement of the rocks is accompanied by a superficial ridge traversing an alluvial terrace. Gilbert, 1898.

1765. Section of Niagara limestone, Cook's quarry, near La Salle, Niagara county, New York. Shows structure described by James Hall, Geology of Fourth District of New York, pages 93 and 94. Gilbert, 1898.

1766. Section in cut of Erie railway, Niagara falls, New York. Shows structure described by James Hall, Geology of Fourth District of New York, pages 93 and 94. Gilbert, 1898.

1767. Weathering of Niagara limestone by solution. A joint face exposed in quarrying southwest of Middleport, New York. Gilbert, 1898.

1768. Weathering of Niagara limestone by solution; old quarry southwest of Middleport, New York. Gilbert, 1898.

1769. Unconformity by erosion. Sandstones and shales of the Medina formation, Niagara gorge. Gilbert, 1898.

1770. Isolated limestone mass at base of Niagara shale, containing "transition fauna" of Ringueberg. Gilbert, 1898.

1771. Section of ripple-mark on Medina sandstone, Lockport, New York. From crest to crest, 23 feet; depth of trough, 29 inches. Gilbert, 1898.

1772. Flagstone in court-house yard, Elyria, Ohio. Shows reticulated ripple-marks. Gilbert, 1898.

1773. Trough of large ripple-mark in Medina sandstone, Niagara gorge, New York. Gilbert, 1898.

1774. Crest of large ripple-mark in Medina sandstone. Quarry near Lewiston, New York. Gilbert, 1898.

1775. Crest of large ripple-mark in Medina sandstone. Quarry in Lockport, New York. Gilbert, 1898.

1776. Diverse cross-bedding associated with large ripple-marks in Medina sandstone. Quarry near Lewiston, New York. Gilbert, 1898.

1777. Quarry face in Medina sandstone. Lockport, New York. Gilbert, 1898.

1778. Quarry face in Niagara limestone. Lockport, New York. The joint face shows weather fracture. Gilbert, 1898.

1779. Shore of lake Ontario at Wilson, New York. Train of shore drift from right, being arrested by bew-pin, begins to accumulate and partly protects bluff from wave attack. Dearth of shore drift under lee of pier favors wave attack; bluff eaten back 45 feet. Bluff contains two tills and cover of laminated clay, a deposit from lake Iroquois. Boulder pavement at top of lower till, indicated by arrow. Gilbert, 1898.

Size, 6 by 7½ inches. Twenty-nine photographed by N. H. Darton, 1898

1780 (424). Triassic conglomerate-sandstone, Garden of the Gods, Colorado. By N. H. Darton, 1898.

1781 (429). Pikes peak through the gateway of the Garden of the Gods, showing Jura-Trias beds. By N. H. Darton, 1898.

1782 (430). Cathedral spires, Garden of the Gods, Colorado. By N. H. Darton, 1898.

1783 (434). Titanotherium sands east of Adelia, Sioux county, South Dakota. By N. H. Darton, 1898.

1784 (443). "Toadstool park," Bad lands near Adelia, Sioux county, South Dakota. By N. H. Darton, 1898.

1785 (444). "Toadstool park," Bad lands near Adelia station, Sioux county, Nebraska. By N. H. Darton, 1898.

1786 (445). Looking down North Platte river at the Wyoming-Nebraska line. By N. H. Darton, 1898.

1787 (465). Granite needles near Harney peak, Black hills, South Dakota. By N. H. Darton, 1898.

1788 (468). Granite needles near Harney peak, Black hills, South Dakota (southern group). By N. H. Darton, 1898.

1789 (472). Cone-in-cone concretion in Pierre shale, southeast of Hot Springs, South Dakota. By N. H. Darton, 1898.

1790 (473). Gypsum in red beds, Hot Springs, Black hills, South Dakota. By N. H. Darton, 1898.

1791 (474). Jurassic sandstone on supposed Triassic red beds, 7 miles south of Hot Springs, Black hills, South Dakota. By N. H. Darton, 1898.

1792 (479). Faulted Middle Jurassic sandstone near Buffalo gap, Black hills, South Dakota. By N. H. Darton, 1898.

1793 (519). Protoceras sandstone area, Big Bad lands, South Dakota. By N. H. Darton, 1898.

1794 (520). Protoceras sandstone area, Big Bad lands, South Dakota. By N. H. Darton, 1898.

1795 (522). Protoceras sandstone area, Big Bad lands, South Dakota. By N. H. Darton, 1898.

1796 (523). Protoceras sandstone area, Big Bad lands, South Dakota. By N. H. Darton, 1898.

1797 (524). Protoceras sandstone area, Big Bad lands, South Dakota. By N. H. Darton, 1898.

1798 (526). Natural bridge, Protoceras sandstone area, Big Bad lands, South Dakota. By N. H. Darton, 1898.

1799 (531). Protoceras sandstone area, Big Bad lands, South Dakota. By N. H. Darton, 1898.

1800 (480). Natural bridge in middle Jurassic sandstone near Buffalo gap, Black hills, South Dakota. By N. H. Darton, 1898.

1801 (506). Big Bad lands of South Dakota, in the vicinity of the Flour trail, looking north. By N. H. Darton, 1898.

1802 (507). Looking west over portion of Big Bad lands of South Dakota near Flour trail. By N. H. Darton, 1898.

1803 (509). Looking west over portion of Big Bad lands of South Dakota from near the Flour trail. By N. H. Darton, 1898.

1804 (510). Looking southwest over a portion of Big Bad lands of South Dakota near Flour trail. By N. H. Darton, 1898.

1805 (515). Sandstone lenses near Flour trail, Big Bad lands, South Dakota. By N. H. Darton, 1898.

1806 (517). Columns of clay capped by sandstone near Flour trail, Big Bad lands, South Dakota. By N. H. Darton, 1898.

1807 (532). Looking down head of South fork of Coral draw, Big Bad lands, South Dakota. By N. H. Darton, 1898.

1808 (536). Big Bad lands of South Dakota in the vicinity of the Flour trail, looking west. By N. H. Darton, 1898.

One (1) view presented by the United States National Museum (George P. Merrill)

Size, 6 by 8½ inches

1809. Polished slab of Orbicular granite in the collection of the United States National Museum. From Slattemösse, Smaländ, Sweden. Dimensions, 22 by 30 inches.

Seven (7) views presented by J. F. Kemp

Size, 5 by 7 inches

1810 (1). Arch of Upper Silurian quartzite forming the "Rainbow," at Iron gate, near Clifton forge, Virginia. The arch is exposed in the valley of the James river. Another stratum of quartzite forms a parallel arch higher up, which does not appear, from lack of distance in taking the view. J. F. K., 1898.

1811 (2). Overthrown fold of Upper Silurian quartzite in Eagle mountain, in the valley of the James river, Virginia. J. F. K., 1898.

1812 (3). One limb of fold of Upper Silurian quartzite forming Rathole mountain, just across the James river from number 2. J. F. K., 1898.

1813 (4). Iron ore mine based on the "gossan" of a pyrrhotite vein, Isabella mine, Ducktown, Tennessee. J. F. K., 1898.

1814 (5). The Mary copper mine, based on a great vein of copper-bearing pyrrhotite, at Ducktown, Tennessee. The vein outcrops in a marked peneplain of mica schists, which is surrounded by a rim of high hills. J. F. K., 1898.

1815 (6). Rocking stone in Bronx park, New York city. By timing the effort to the period of the stone a man can make the top of the stone describe an arc of about 3 inches. J. F. K., 1898.

1816 (7). Glacial furrows, Bronx park, New York city. The furrows are not far from the rocking stone, but they have no connection with it. They strike in a northwesterly direction across the foliation of the gneisses. J. F. K., 1898.

Fifty-eight (58) views presented by Geological Survey of Iowa

Size, 4½ by 7½ inches

1817 (1). South of Cedar river, Linn county, Iowa. Ultimate ramification of dendritic drainage on loess mantle of Kansan drift sheet. Cedar Rapids sheet, topographical atlas, United States Geological Survey.

1818 (2). Topography of Kansan drift sheet, showing slopes of larger ravines. South of Cedar river, Linn county, Iowa. Cedar Rapids sheet, topographical atlas, United States Geological Survey.

1819 (3). Topography of Kansan drift sheet loess-mantled spatulate gullies. South of London, Cedar county, Iowa.

1820 (4). On Walnut creek, Scott county, Iowa. In Kansan drift sheet with loess mantle. Iowa Geological Survey, volume ix.

1821 (5). Kansan-loess topography, showing even sky line and spatulate valleys. Dixon, Scott county, Iowa. On farm of Ketelson. Iowa Geological Survey, volume ix.

1822 (6). Steffen's quarry, Cleona township, Scott county, Iowa. Pitted rock surface beneath Kansan drift. False bedding of Leclaire limestone. Iowa Geological Survey, volume ix.

1823 (7). Illinoian topography. North of Buffalo, Scott county, Iowa. Showing tabular divides on initial drift plain and miners sinking shaft for coal. Iowa Geological Survey, volume ix.

1824 (8). Topography of Iowan drift sheet. Drift plain with boulder and paha hills, near Lowden, Cedar county, Iowa.

1825 (9). From chapel tower of Cornell College, looking north-northeast. Iowan drift plain with paha ridges in distance. Mechanicsville sheet, topographical atlas, United States Geological Survey.

1826 (10). Paha north of Allens Grove, Scott county, Iowa, looking north. Davenport sheet, topographical atlas, United States Geological Survey; Iowa Geological Survey, volume ix.

1827 (11). The Stanwood paha, showing marshy ground which surrounds it. Eleventh Annual Report, United States Geological Survey, page 404; Tipton sheet, topographical atlas, United States Geological Survey.

1828 (11*a*). Stanwood paha, looking north. Eleventh Annual Report, United States Geological Survey, page 404; Tipton sheet, topographical atlas, United States Geological Survey.

1829 (12). Mount Vernon paha from south. Iowa Geological Survey, volume iv, pages 181-184.

1830 (13). Paha between Mount Vernon and Lisbon, Iowa.

1831 (14). Gallegher paha, northeast of Long Grove, Iowan frontier, Scott county. Hummocks of loess and sand, with pahoid orientation. Iowa Geological Survey, volume ix; Davenport sheet, topographical atlas, United States Geological Survey.

1832 (15). Sandhills, Iowan frontier, northwest of Princeton, Scott county, Iowa. Iowa Geological Survey, volume ix.

1833 (16). Pond among sandhills of Iowan frontier, Princeton township, Scott county. Iowa Geological Survey, volume ix.

1834 (17). Erosion gullies in loess mantle on Illinoian drift sheet, Princeton township, Scott county. Iowa Geological Survey, volume ix.

1835 (18). Vertical cleavage of loess, Bielers quarry, Cedar valley, Iowa.

1836 (19). Swallows' nests in loess, Clinton, Iowa.

1837 (20). Lingulate lobes of heavy loess near Iowan frontier, northwest of Princeton, Scott county, Iowa. Iowa Geological Survey, volume ix.

1838 (21). Gorge of Wapsipinicon, northeast of Dixon, Scott county, Iowa. Iowa Geological Survey, volume ix.

1839 (22). Gorge of Wapsipinicon, southeast of Big Rock, Scott county. Iowa Geological Survey, volume ix.

1840 (23). View across wide floodplain of Wapsipinicon valley below gorge shown in No. —, looking north. Leclaire atlas sheet, United States Geological Survey. Geology of Scott county, volume ix, Iowa Geological Survey.

1841 (24). Wide floodplain of Wapsipinicon river, Scott county, Iowa; seen from roadway cut in loess-mantled hills of Iowan frontier. Leclaire sheet, topographical atlas, United States Geological Survey; Iowa Geological Survey, volume ix.

1842 (25). View down Cedar river from below Cedar springs (Palisades). At head of gorge of Cedar river, cut in Leclaire limestone, near Mount Vernon, Iowa.

1843 (26). Broad valley of Cedar river below gorge south of Mount Vernon, Iowa. Mechanicsville sheet, topographical atlas, United States Geological Survey.

1844 (27). Gorge in Cedar river, Cedar bluff, Iowa. The rock hill at left parted from the rocky ridge at right by present channel of river rises from an ancient and wide floodplain so low that loess have been built to protect it from floods. Mechanicsville sheet, topographical atlas, United States Geological Survey.

1845 (28). Valley of Mud creek near mouth, Scott county, Iowa. Channel of "Wilton river," an ancient waterway probably occupied by the Mississippi during Illinoian invasion. Iowa Geological Survey, volume ix; Durant sheet, topographical atlas, United States Geological Survey.

1846 (29). Channel of "Wilton river," an ancient waterway to which the Mississippi is supposed to have been deflected during the Illinoian invasion. Now occupied in Scott county by Mud creek and Elkhorn creek. View at divide between the creeks which is constituted at marshy ground with a few small ponds lying but slightly above general level of channel. Iowa Geological Survey, volume ix; Durant sheet, topographical atlas, United States Geological Survey.

1847 (30). Contact of Niagara limestone (Silurian) and Hudson River shales (Ordovician). Above Lyons, Iowa.

1848 (31). Contact of Niagara limestone and Maquoketa shales (Silurian and Ordovician). Lyons, Iowa. Showing parallelism of the Silurian and Ordovician strata and the spheroidal weathering of the latter.

1849 (32). Chert layers in Delaware beds. Niagara limestone, Lyons, Iowa. Banks of Mississippi river.

1850 (33). "Massif," 90 feet high, of Leclaire limestone (Viola type), Niagara. Cedar river near Mount Vernon, Iowa. Iowa Geological Survey, volume 4, pages 129, 130.

1851 (34). "Massif" of Leclaire limestone (Viola type). Palisades below Minots, Cedar river, Mount Vernon, Iowa.

1852 (35). "Massif" of Le Claire (Viola) limestone quarried for lime. Schmidt's quarry. Southwest of Dixon, Scott county, Iowa. Reference, Geology of Scott county, Geological Survey, volume ix. Obscure false bedding appears on right of mound.

1853 (36). Dips of Leclaire (Viola type), Upper Palisades, Cedar river, near Mount Vernon, Iowa. Supposed examples of false bedding.

1854 (37). "Massif" of Leclaire limestone (Viola type) on left, into which run planes of false bedding from right. Cedar Valley lime quarries, Cedar county, Iowa.

1855 (38). Unstratified mound in Leclaire limestone (Anamosa type), near Lowden, Iowa.

1856 (39). Leclaire limestone near Massillon, Iowa. Illustrating the breaking down of cliffs along joint planes.

1857 (40). Ferruginous stains. Slab of Anamosa limestone, Leclaire stage of Niagara, from Mount Vernon quarry, Iowa.

1858 (41). Bieler's quarry, Cedar Valley, Iowa, showing horizontal and even bedding of Anamosa stone. Leclaire stage of the Niagara.

1859 (42). Cliff at Kenwood, Iowa. The lower 8 of feet Otis limestone, the basal member of the Devonian series in Iowa. Above the Otis is seen the Independence shale with associated limestones. Iowa Geological Survey, volume iv, pages 142, 143.

1860 (43). Kenwood bluff on Indian creek, Kenwood, Iowa. Fayette breccia at highest point. Otis limestone. Iowa Geological Survey, volume iv, pages 142, 143.

1861 (44). Independence shale. Linn, Linn county, Iowa. The light-colored clay shown in this landslip is the only known fossiliferous outcrop of these shales. Fayette breccia on either side.

1862 (45). The Lower Davenport beds. Devonian. Mouth of Duck creek, Scott county, Iowa. Reference, Geology of Scott county, Iowa Geological Survey, volume ix.

1863 (46). Brecciated beds of Lower Davenport limestone, Rock Island, northwest shore, Illinois. A flexed and broken fragment.

1864 (47). Breccia in Lower Davenport beds, Rock Island, Illinois.

1865 (48). Breccia in Lower Davenport beds, Rock Island, Illinois. Initial flexures.

1866 (49). Breccia, Linn, Linn county, Iowa. General view. This brecciated horizon, known as "the Fayette breccias," involves the following members of the Devonian series: Cedar Valley stage, *Spirifer pennatus* beds; Wapsipinicon stage, Upper Devonian beds, Lower Davenport beds; Independence shales. Iowa Geological Survey, volume iv, pages 157–166.

1867 (50). Breccia, Linn, Linn county, Iowa. Lowest phase, natural size. Iowa Geological Survey, volume iv, pages 157–166.

1868 (51). Breccia, Linn, Linn county, Iowa. Second phase. Chiefly fragments of Lower Davenport limestone. Iowa Geological Survey, volume iv, pages 157–166.

1869 (52). Breccia, Linn, Linn county, Iowa. Close view. Complex brecciation in large fragments. Iowa Geological Survey, volume iv, pages 157–166.

1870 (53). Breccia, Linn, Linn county, Iowa. Illustrating differential weathering of breccia, largely made up of Independence shales (buff, Kenwood phase), forming abundant talus and breccia formed of numerous fragments of Lower Davenport limestone, with sparse matrix. Iowa Geological Survey, volume iv, pages 157–166.

1871 (54). Breccia, Linn, south end of cut. Showing tilting.

1872 (55). Breccia, Linn, Iowa. Showing large blocks of Upper Davenport limestone retaining approximately their plane of deposition. The sides of these tilted blocks are usually affected with slickensides.

1873 (56). Breccia, Linn, Linn county, Iowa. Close view. Iowa Geological Survey, volume iv, pages 157–166.

1874 (57). Coal Measures shales in Lower Davenport limestone, Davenport, Iowa. Roof of cavern partially preserved. Iowa Geological Survey, volume ix; Geology of Scott county, Iowa.

Four (4) views presented by T. C. Hopkins

Size, 3½ by 4½ inches

1875 (1). View on the Ohio River bluff opposite Beaver, showing concentric weathering in shale. The weathering from the joints shows concentric peeling off on a large scale, with smaller concretionary masses inside. T. C. Hopkins, State College, Pennsylvania, August, 1897.

1876 (2). View on the Ohio River bluff opposite Beaver, Pennsylvania, showing concentric weathering in shale (Coal Measures). T. C. Hopkins, State College, Pennsylvania, August, 1897.

1877 (3). View of a shale bluff on Block House run, New Brighton, Pennsylvania, showing concentric weathering. Shale of lower Coal Measures. T. C. Hopkins, State college, Pennsylvania, August, 1897.

1878 (4). View showing concentric weathering in shale (Coal Measures) on the Ohio River bluff at Rochester, Pennsylvania. T. C. Hopkins, State College, Pennsylvania, August, 1897.

Announcements regarding the annual dinner were made by Dr E. O. Hovey and concerning mail and railroad certificates by Professor J. F. Kemp.

The first two papers of the morning session were read by the author and discussed together.

RELATIONS OF TERTIARY FORMATIONS IN THE WESTERN NEBRASKA REGION

BY N. H. DARTON

SHORELINES OF TERTIARY LAKES ON THE SHORES OF THE BLACK HILLS

BY N. H. DARTON

In discussion of the two papers remarks were made by G. K. Gilbert, G. M. Dawson, and A. C. Gill.

The following paper was read:

GENERAL GEOLOGY OF THE CASCADE MOUNTAINS IN NORTHERN WASHINGTON

BY I. C. RUSSELL

Remarks were made by Bailey Willis, S. F. Emmons, G. M. Dawson, and the author.

The Society then adjourned for the noonday recess and lunch and reconvened at one o'clock p m.

As introductory to the paper by Mr McGee, an address was made on the archeology of California by Mr W. H. Holmes, expressing strong doubts of the credibility or genuineness of the reputed evidences of man in the Tertiary of California. This was followed by

GEOLOGY AND ARCHEOLOGY OF THE CALIFORNIA GOLD BELT

BY W J MC GEE

The paper was discussed by S. F. Emmons, J.W. Powell, J. A. Holmes, H. T. Fuller, Angelo Heilprin, the author, and Professor William H. Brewer, of New Haven, Connecticut, a visitor. A portion of the matter of the paper and the address by Professor Holmes is published in the American Anthropologist (new series), volume 1, 1899, pages 107–121.

Vice-President Emerson assumed the chair, and, in the absence of its author, the next paper was read by title.

GEOLOGY AND PHYSIOGRAPHY OF THE WEST INDIES

BY ROBERT T. HILL

In place of the above paper the following paper was given place:

PHYSIOGRAPHY AND GEOLOGY OF REGION ADJACENT TO THE NICARAGUA CANAL ROUTE

BY C. W. HAYES

Remarks were made by G. K. Gilbert and Professor William H. Brewer. The paper is printed as pages 285–348 of this volume.

The next paper was read by title:

SURFACE FEATURES OF NORTHERN KENTUCKY

BY MARIUS R. CAMPBELL

The two following papers were then read:

AN UNRECOGNIZED PROCESS IN GLACIAL EROSION

BY WILLARD D. JOHNSON

GEOLOGY OF THE YOSEMITE NATIONAL PARK

BY H. W. TURNER

President Stevenson at this point resumed the chair. The discussion of the last two papers was begun, but was soon postponed until the afternoon of Friday (see page 491).

The following three papers were read without discussion:

GOLD MINING IN THE KLONDIKE DISTRICT

BY J. B. TYRRELL

GLACIAL PHENOMENA IN THE CANADIAN YUKON DISTRICT

BY J. B. TYRRELL

The paper is printed as pages 193–198 of this volume.

THE NASHUA VALLEY GLACIAL LAKE

BY W. O. CROSBY

No evening session was held, but the Fellows of the Society with a few guests had the annual dinner at the hotel Logerot.

Session of Friday, December 30

The Society met at 10 o'clock a m, President Stevenson in the chair.

The Secretary announced that the Council had selected Washington as the place of meeting for December, 1899.

The scientific program was resumed with the following paper:

ORIGIN OF THE GRAHAMITE IN RITCHIE COUNTY, WEST VIRGINIA

BY I. C. WHITE

Remarks were made by A. P. Coleman, J. S. Diller, J. F. Kemp, M. A. Wadsworth, J. A. Holmes, and the author. The paper is printed as pages 277–284 of this volume, under the title "Origin of Grahamite."

The next paper was

GEOLOGICAL STRUCTURE OF THE IOLA GAS FIELD

BY EDWARD ORTON

Remarks were made by the President, J. F. Kemp, and I. C. White. The paper is printed as pages 99–106 of this volume.

The following paper was then read:

CONSHOHOCKEN PLASTIC CLAYS

BY T. C. HOPKINS

On the hill near Conshohocken is one of the most interesting clay deposits in the state of Pennsylvania—interesting to the geologist because, with possibly one exception, it is unlike any other deposit in the state, and, further, for its remarkable resemblance to clay beds in other states. It was a matter of great surprise to the writer to find that there was no description nor even mention of these clays in any of the state geological reports, nor in fact in geological literature anywhere, and this despite the fact that they have had an important economic usage for 50 years.

The clays occur on the hill north of Conshohocken, north of the Schuylkill river, about 13 miles above Philadelphia. The clay has been exploited about the little village of Harmarville, along the pike between Conshohocken and Plymouth, and at several points eastward along the ridge to and beyond Barren or Lafayette hill, covering an area several square miles in extent.

The clay rests upon a blue (in places white and blue) limestone supposed to be of the age of the Trenton period. The limestone outcrops in several places in the proximity of the clay and has been quarried as marble quite extensively. A trap dike crosses the area, and the trap rock is exposed in several places. Iron ore and sand are still more intimately associated with the clay, and both have been mined quite extensively.

The clay, which is a tough, plastic, refractory one, lies in inequalities on the limestone. It is quite variable in color and character at different points. One pit may show clay, while another close by will contain nothing but sand, and from the same pit is taken bright red clay, variegated red and gray, white, black, and yellow clays, the colors not regularly banded, but quite irregularly mixed. In some places there are considerable bodies of uniform color, while at other points the colors are quite intricately mixed.

The variation in color and character of the materials probably may be best shown by comparing the following detailed sections, the location of which is shown on the accompanying plan, drawn to scale, on which the elevation above tide is shown.

Numbers 1, 2, and 3, the openings farthest southwest, are sand pits from which foundry sand has been mined. The upper part, 2 to 3 feet thick, consists of yellow sand, containing many quartz fragments and fragments of iron ore, which apparently rests unconformably upon a light, yellow-colored, clean, quartz sand with rounded grains, like beach sand. In one opening thin, irregular layers of fine gravel occur in this sand 10 feet and 15 feet from the top along with a few small pockets of white clay. The sand shows false bedding in places, and in one of the openings the sand is a light, feathery, micaceous variety.

Number 4 is a clay pit worked to a depth varying from 50 to 60 feet. There is at the surface a layer 3 to 6 feet thick of yellow sand, in a few places running to a depth of 15 feet. This is underlain by red variegated clay, a brilliant red clay, a black clay containing much charcoal or lignite, and a dove-colored clay. Both the dove-colored and the black clays turn lighter on exposure. These clays are not regularly bedded, but quite irregular in their occurrence. Thus the red clay runs more than half way down the pit on one side, while on the other the black clay extends nearly to the surface.

Number 5 is an abandoned iron mine which shows a white clay containing large quantities of iron ore and numerous pebbles and cobblestones—some rounded, some angular, and some subangular—the whole mass resembling in a striking manner beds of glacial drift. This mass of material shows a coarse lamination in places, a lamination strikingly unconformable with a finely laminated sandy clay that underlies it in one place.

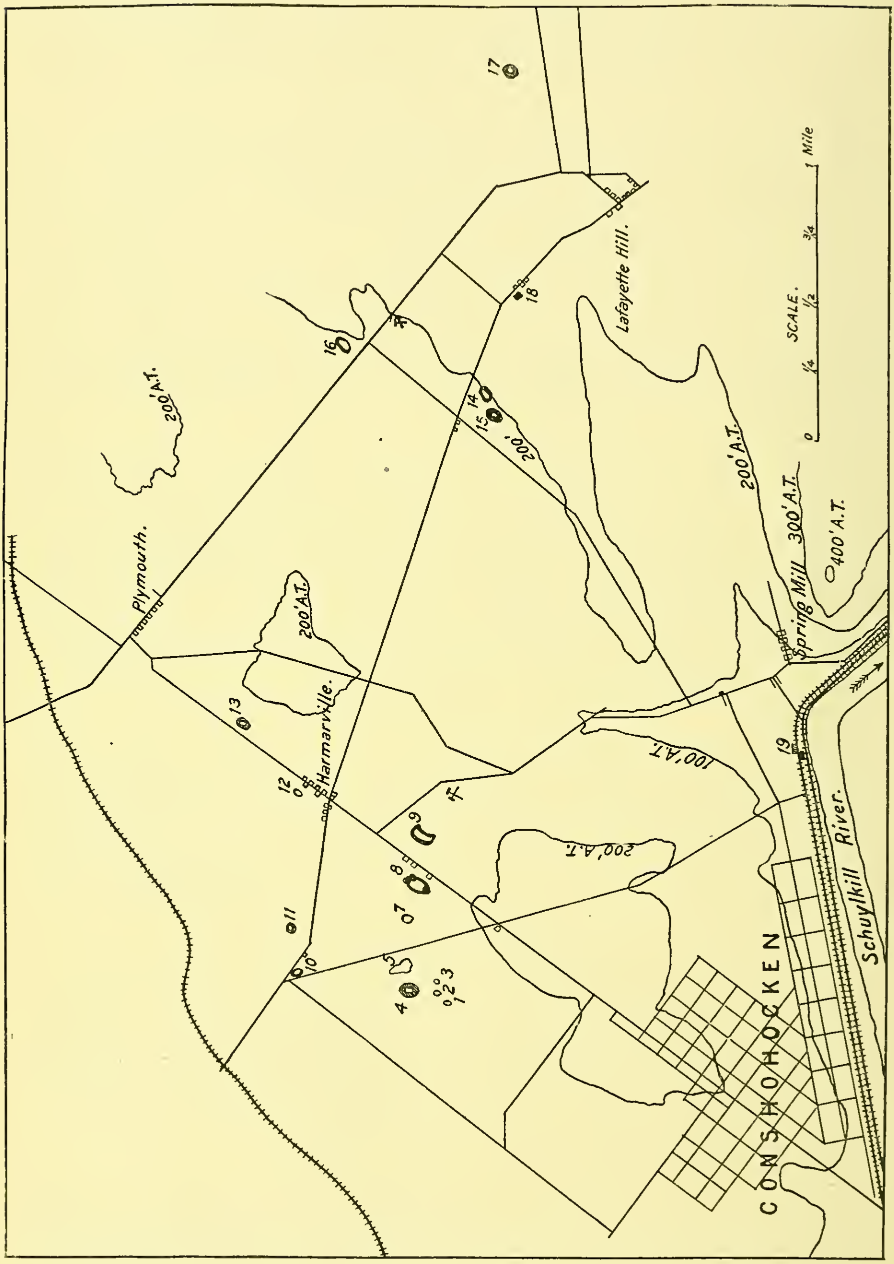

FIGURE 1.—*Location of the Conshohocken plastic Clays of Montgomery County, Pennsylvania*

Number 6 is an abandoned iron mine, overgrown.

Number 7 is a sand pit apparently about 20 feet deep.

Number 8 is a large clay pit, where several shafts have been sunk recently around the border of the pit, showing fresh exposures. These show a layer of yellow sand, clay, and pebbles at the top, varying from two to eight feet, underlying which is a bed of varying thickness consisting of variegated, red, red and gray mixed, and black clay, containing many pebbles. Beneath this is a clay, red, gray, black, and dove-colored, running to a depth of 40 to 50 feet. The clays are not regularly banded, but the colors are irregularly intermixed. The black clay which predominates toward the bottom contains large quantities of charcoal or lignite, fragments of limbs and twigs varying in size from a fraction of an inch to several inches in diameter. No leaves nor bark were observed.

Number 9 is a large pit containing clay, sand, and gravel in different portions. Large quantities of iron ore were removed from this opening a number of years ago. At the west end is a deposit of clean, sharp sand about 20 feet deep that has been quarried for foundry purposes. Near the middle of the opening is a shaft about 25 feet deep showing alternating layers of sand and light-colored clay; east of that a few yards the clay disappears, and the material is coarse sand and fine gravel; a few yards farther on is an opening in the variegated red clay. All of these sections are at about the same level, but none of them go through either the sand or clay, so the thickness is not known. About 50 yards south is a large marble quarry, where the limestone extends to the surface and has been quarried to a depth of 100 feet or more.

Number 10 is an abandoned brick yard where variegated and white clays were worked. It is now overgrown.

Number 11 is a small pit where white clay and white sand occur together. The white clay is overlain by five to eight feet of yellow sandy loam which contains fragments of quartz and pieces of red and brown hematite. The shaft penetrates about 15 feet into the white clay, but how much thicker it is could not be ascertained. Between number 11 and number 12 a thick deposit of white clay is reported.

Numbers 12 and 13 are old iron mines, from both of which considerable red and red variegated clay has been removed, but both mines are now abandoned.

Number 14 is an old iron mine from which white sand has been removed.

Number 15, a few yards farther south, shows two to five feet of brownish sandy clay at the top, banded blue and gray clay underneath, 20 feet or more in thickness. It shows a faint schistose structure in places as though it was decayed schist. About a quarter of a mile north of the last mentioned opening is a large iron mine.

Number 16, one of the largest openings on the hill is an ore pit, from which large quantities of clay were taken, and between the iron mine and the clay bank, number 14, there is an old marble quarry.

Number 17 is a short distance northeast of Lafayette hill, on the farm of Mr George Rapine. It is a shaft in the light and red variegated plastic clay which has been mined to some extent for use in the Barren Hill terra-cotta works. Some exploitation has been done here, but the report of it is too indefinite to give a correct estimate of the extent of the bed. The owner states that the clay follows a narrow east-and-west belt, and a short distance north exploitation pits showed nothing but sand.

Number 18 is the Barren Hill terra-cotta works, where these plastic clays have been used for nearly 50 years.

These are all the openings that had been made in the clay as late as August, 1898, although there is little doubt that many of the wells in this vicinity have been sunk into it. The area of the clays is probably not much larger than that outlined by the pits shown on the plat. Inquiry and a hasty examination failed to discover any similar deposits of red and variegated plastic clay in Pennsylvania except the deposit at Turkey Hill, a few miles southwest from Trenton, in the extreme eastern part of Pennsylvania, and 25 or 30 miles from Conshohocken, at which point red and variegated clays were mined several years ago and shipped to the Trenton potteries. The mines have not been operated for several years, as they are two far from the railroad to compete with the New Jersey clays.

The Conshohocken clays resemble the plastic clays of New Jersey, Long Island, and Marthas Vineyard. The similarity in appearance is sufficient to suggest that they may have been formed at the same time, at least under similar if not the same conditions and from materials having probably the same source.

To the best of my knowledge, no fossils have been found in these clays except the lignite, consisting of fragments of branches, which are fairly well preserved, but which rapidly crumble on exposure, and until further paleontologic evidence is found any correlation of these clays with deposits elsewhere will no doubt be attended with uncertainty.

The clays have been used in the terra-cotta works at Barren hill and Spring mill for making sewer pipe; they have been shipped to Reading and Royersford for making firebrick and stove linings. They have been used at Norristown for furnace lining, and to some extent for making glass pots. They are quite plastic and highly refractory, and the wonder is that they have not been used more extensively. The reason for their limited usage may be that they are little known outside of the immediate locality, and they are too remote from the railroad to compete successfully with the New Jersey clays.*

The next paper was:

REMARKABLE LANDSLIP IN PORTNEUF COUNTY, QUEBEC

BY GEORGE M. DAWSON

Contents

Locality and Consequences of the Landslip

On May 7, 1898, a landslip occurred on the Rivière Blanche, a tributary of the Sainte Anne de la Pérade, parish of Saint Thuribe, Portneuf county, Quebec. The

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*More extended field observations carried on since the above was in type throw considerable light on the origin of these clays. The results will be incorporated in reports by the writer on the clays of eastern Pennsylvania in the annual reports of Pennsylvania State College.

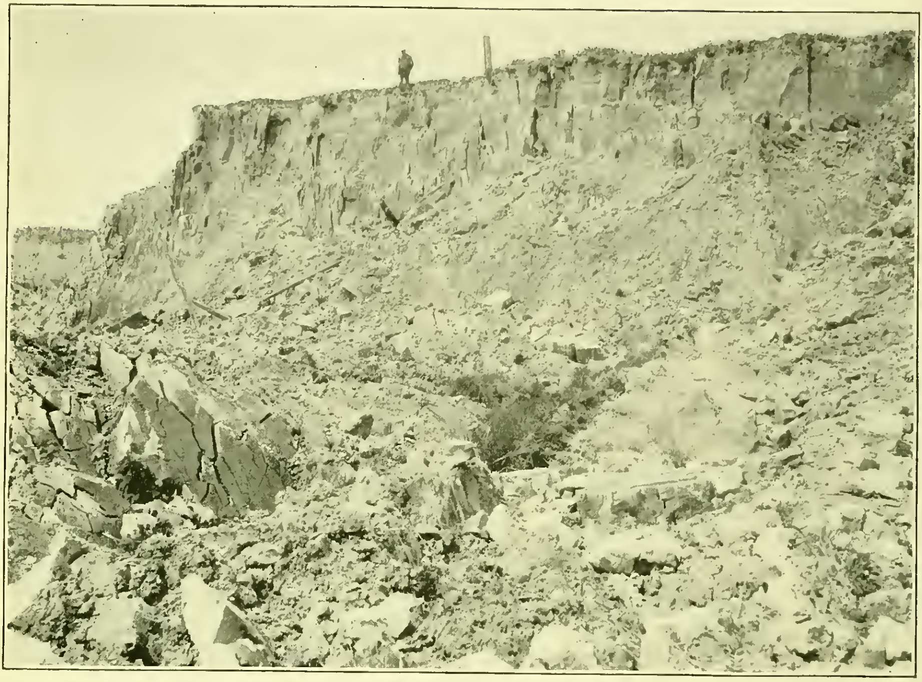

FIGURE 1.—CLAY CLIFFS AT EASTERN END OF LANDSLIP AREA

FIGURE 2.—BLANCHE VALLEY OPPOSITE LANDSLIP, WITH LANDSLIP OUTLET IN DISTANCE

RIVIÈRE BLANCHE LANDSLIP

slip took place on the east side of the river, at a distance of 3 miles from the village of Saint Casimir. The results were disastrous to the farmers whose property was affected, one life was lost, two inhabited houses, a school-house, two barns, and several outbuildings were destroyed or engulfed, and cattle, horses, and other live stock perished.

Examination made

On May 29 I visited and examined the locality, taking some photographs of the scene, and a few days later, at my request, Mr R. Chalmers, of the Geological Survey, accompanied by Mr J. Keele, made a closer study of the circumstances as well as an approximate survey of the place, and procured additional photographs. The following brief description is based partly on my own observations, in part on those of Mr Chalmers, and is intended merely to outline the chief facts of interest, from a geological standpoint, respecting a mode of denudation that appears to have been not uncommon in the clay-floored plain of some parts of the Saint Lawrence valley.

Character of the Country

At the place in question, the Rivière Blanche, a small stream, occupies a valley running from north to south, about 1,000 feet wide, between sloping banks, 25 to 35 feet high, and nearly uniform in this respect. The surface of the country in the vicinity is for the most part under tillage, and is practically level to the eye, being a terrace-flat or plain composed of the marine Pleistocene deposit known as Leda clay, the whole thickness of which is not here anywhere shown. The clay is occasionally covered by arenaceous deposits a few feet thick and referable to the Saxicava sands.

To the north of and adjoining the wide crater-like depression produced by the landslip here particularly described there is, however, an irregular depressed area of nearly the same size, now under tillage, that evidently represents the site of a much earlier slip of the same character. Still farther to the north, and at a distance of 50 chains from the recent slip, the road, which runs parallel to the river valley and near it, crosses a low ridge of boulder clay. This material may be presumed to underlie the Leda clay elsewhere, but the subjacent rock is nowhere seen in the vicinity.

Mode and Extent of the Movement

A small runnel of water appears to have entered the Blanche valley at the point where the material of the landslip subsequently found issue, and I was informed that previous to the main slip a small slide had been noted to occur at this spot. At half past five in the morning the inhabitants were alarmed by the movement of the soil, which then suddenly began and continued for three or four hours. The immediate bank of the river valley appears in the first place to have given way along a front of about 200 feet in width, and the gap thus made rapidly extended inland, forming an opening through which a great body of clay behind rushed tumultuously out into the Blanche valley. At a short distance from the bank of the valley the width of the area affected greatly enlarged, the sides of the depression collapsing and falling into the gulf, until a crater-like hollow of bottle-shaped outline and opening on the valley by a narrow neck was produced.

The inhabitants on the spot were so much alarmed that they naturally did not observe the actual progress of the landslip with great precision, but eye-witnesses describe the passage of blocks and pyramids of clay through the orifice to the river valley as being very swift and resembling steamers in motion on a river. The occurrence, in fact, may be said to have resembled the bursting out into the valley of a lake of liquid mud, bearing with it outstanding and unbroken blocks of clay detached from the sides of the collapsing area.

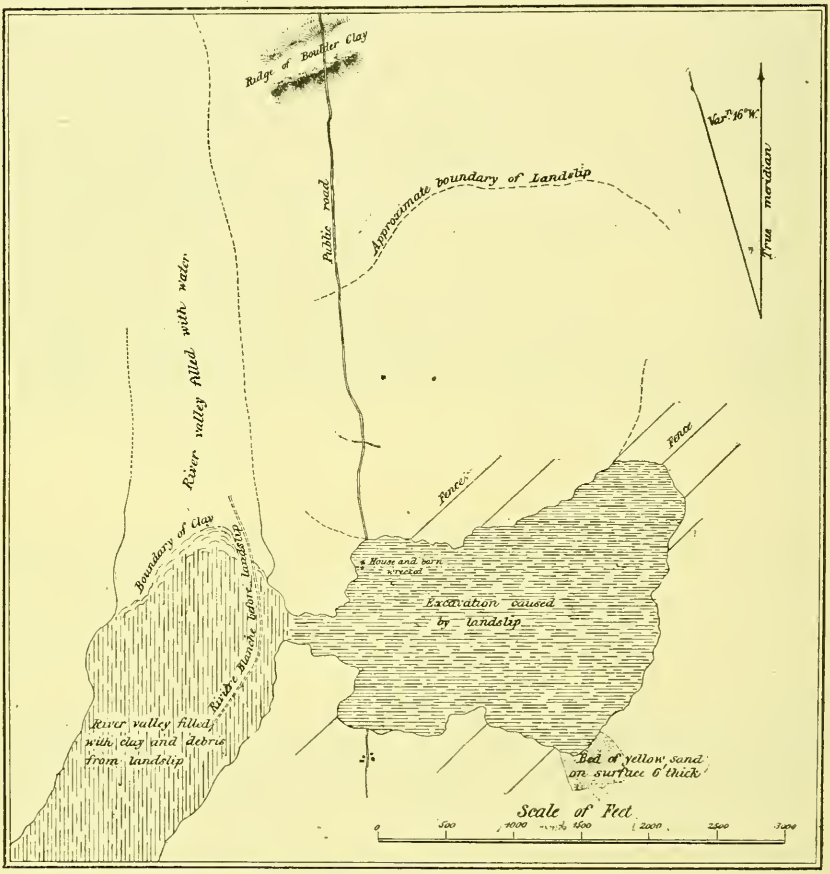

FIGURE 1.—*Sketch-plan showing Area of Landslip (horizontal lining), Part of Clay-filled River-valley (vertical lining), and approximate Boundary of an ancient Landslip of the same Kind*

On entering the Blanche valley the flood of clay spread upstream for some 500 or 600 feet, ponding back the river water, but the greater part, descending the valley for nearly two miles, filled it for that distance to a maximum depth of fully 25 feet, causing the destruction of the rich meadows along the valley, besides that of the agricultural lands immediately affected by the collapse.

When examined by me, the actual landslip was represented by a depressed area bordered by clay cliffs from 15 to 30 feet high, 1,700 feet in maximum width, with a greatest length of 3,000 feet and an area of 86 acres. The floor of this depression was formed by irregular mounds, pyramids, and blocks of clay, with trees, portions of fences, and other debris and small pools of water here and there; although it is stated that very little water was seen during the actual movement of the mass. The wrecks of trees coming from a wood-lot, part of which still remains near the head of the crater, showed very clearly the direction of flow of the mass. The channel of the Blanche below the orifice of the slip was entirely filled, and the water spread from bank to bank of the valley amid mounds and blocks of clay and debris that stood above it.

Amount of Material involved

The quantity of material which thus poured suddenly out into the Blanche valley is approximately estimated at 93,654,000 cubic feet, with a total weight, according to the specific gravity determined, of about 5,572,413 tons of 2,000 pounds.

The slope of the original surface from the head of the collapsed area to the point at which the road formerly passed, near the entrance to the narrow outlet, was, according to barometric observations by Mr Chalmers, about 10 feet only. The approximate difference between the average level of the bottom from the head to the present water level in the Blanche valley, according to the same authority, is between 20 and 25 feet, while the slope of that part of the Blanche valley from the orifice of the slip to the extremity of the flood of clay is not much more than 30 feet.

Explanation of the Catastrophe

The light slopes indicated by the above figures show that the mass of clay must have simulated a liquid body when in motion. Mr Chalmers suggests that a lower bed of the clay, in consequence of the impermeability of the subjacent boulder clay, became exceptionally saturated, forming a sliding plane upon which the more coherent overlying masses moved down. This would be in conformity with the explanation usually (and probably in most cases correctly) given for landslips, and it seems very likely that something of the kind may have been concerned in the initiation of the slip here described where it began on the bank of the Blanche valley. It appears to me, however, that the great and sudden discharge of clay in this case should rather be attributed to the character of the water-saturated mass as a whole, particularly as no evidence was found of any specially permeable or fluent bed and no underlying surface either of boulder clay or rock is anywhere exposed. It will be noted that this landslip differs very markedly in character from the ordinary form, in which the subsidence occurs along an extended front.

Three representative specimens of the clay, collected by Mr Chalmers while still in a nearly saturated condition were submitted to a careful examination in the laboratory of the Survey under Doctor Hoffmann's supervision. A mean of the results obtained shows the specific gravity of the clay as received to have been 1.912, equivalent to a weight of 119.5 pounds to the cubic foot. The clay as received was found capable of absorbing a small additional amount of water, varying from 7.0 to 0.2 per cent by weight. Apart from the water, it consisted of 35.5 per cent of argillaceous matter and 43.3 per cent of silt. When fully saturated it contained on the average, which varied little in the three samples, 23.5 per cent of water by weight or nearly 50 per cent by volume.

It will be noted that the Leda clay here contains a considerable proportion of silt as compared with the argillaceous matter proper, bearing out an observation made to the same effect on inspection of the locality. The large amount of silty matter present would render the clay unusually permeable, and it seems, therefore, to be probable that the water saturated the mass by descending directly through it from the surface, in a manner which would not have been possible in the case of the more purely argillaceous clays of the same age usually found.

In Rankine's Civil Engineering it is stated that "the presence of moisture in earth to an extent just sufficient to expel air from its crevices seems to increase its coefficient of friction slightly ; but any additional moisture acts like an unguent in diminishing friction and tends to reduce the earth to a semifluid condition, or to the state of mud." It appears probable that in this particular instance the silty clay, surcharged with water, stood in a condition of unstable equilibrium, retaining its solidity merely by virtue of its unbroken molecular texture, and that at the moment in which it became subject to internal movement this texture gave way and it lapsed into a nearly liquid mass, the particles rearranging themselves with some freedom in the water previously locked up in its pores.

The fact that many clays when once completely dried and then immersed in water lose their plastic character and crumble down into an incoherent mud, shows that the natural texture is an important element in their coherence and plasticity, and one which does not appear to have been fully recognized in connection with experiments on clays and soils.

The high specific gravity of the fluent portion of the mass in this case, no doubt enabled it to carry the unbroken blocks of clay along that were supplied by the collapsing sides of the crater-like depression which was immediately formed, and when not subjected to stress these blocks continued to retain their original firmness and form.

The fact that the great mass of moving material was discharged through a comparatively narrow orifice, shows that the bank of the valley through which it passed was much firmer in character than the clay forming the subsoil of the plain behind. This no doubt arose from the natural drainage of the clay along the bank preventing its complete saturation. The same explanation no doubt accounts for the northern limit of the collapsed area occurring along the line where the surface begins to slope down toward the hollow of the old landslip already mentioned, but the limiting causes on the east and south are not clearly apparent.

Inquiries made on the spot showed that no excessive rains had occurred immediately preceding the slip, but that a great depth of snow lay upon the ground during the latter part of the preceding winter. These statements are confirmed by the meteorological observations made at Quebec, about 40 miles distant, which have been obligingly furnished by Mr R. F. Stupart, director of the meteorological service. From these it appears that the total precipitation (in rain or melted snow) for the months of November and December, 1897, and in January, March, and April, 1898, was slightly below the normal for the past 24 years, but that in February, 1898, it was two inches above the average, in the form of an abnormal excess of snowfall in that month of 17.9 inches, the total snowfall for February, being 44.2 inches. The ground was thus heavily burdened with snow in the later winter. During April most of this melted and the soil itself thawed, permitting

Figure 1.—North Edge of Landslip Area, viewed Eastward from near the Outlet

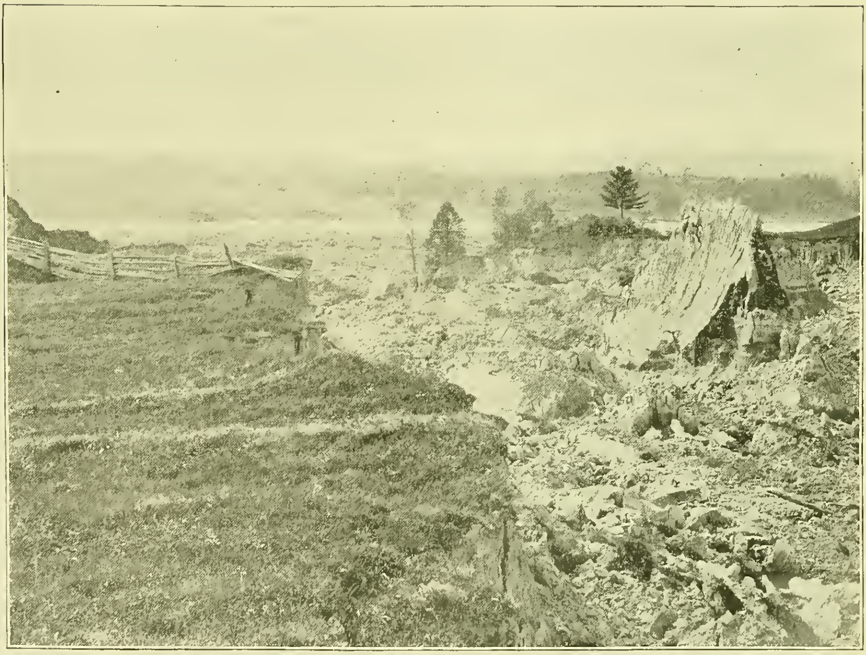

Figure 2.—Outlet of Landslip, looking toward Blanche Valley

RIVIÈRE BLANCHE LANDSLIP

the absorption of the water and resulting, early in May, when the clay beds had thus become thoroughly saturated, in the landslip which has been described.

PROTECTION FROM SIMILAR DISASTERS

The only way in which the recurrence of such slips in regions of country of the same character and under similar exceptional conditions of precipitation can be guarded against appears to be the provision of effective surface drainage, such as to carry off the excess of water before the rather slow process of absorption by the subjacent clays can take place.

SIMILAR OCCURRENCES IN THE SAME REGION

In a paper entitled "L'Eboulis de Saint Alban,"* Monseigneur Laflamme has given an excellent account of a landslip that occurred on April 27, 1894, on the Sainte Anne river, distant about 7 miles only from that above described and affecting similar deposits of the same plain, although at Saint Alban a large part of the slide consisted of the Saxicava sands, there developed in great thickness above the Leda clay.

The landslip at Saint Alban was also much larger than that on the Blanche, an area more than 3 miles in length along the river and about 7,700 feet in greatest width having moved bodily down into the valley. Five or six farm-houses were destroyed or swallowed up, four lives were lost, and the entire mass of the slide is estimated at from 600,000,000 to 700,000,000 cubic feet.

The landslip at Saint Alban was also different in its cause and character. The river was first dammed by a comparatively small slide, and when the water thus held back eventually broke through, its undermining action on the high banks of the valley was such as to precipitate the collapse of the much greater area above noted.†

A brief description of a landslip almost identical in character with that of the Blanche and affecting a similarly situated part of the same Saint Lawrence plain has, however, previously been given by Sir William Logan in a paper read before the Geological Society of London in 1842.‡

This landslip occurred on the Maskinongé river, about 50 miles to the southwest of the Rivière Blanche, on April 4, 1840, and was examined by Logan in the following autumn. Like that on the Blanche, its outlet through the bank of the valley was narrow, and its greatest width, about 600 yards, occurred at some distance back from this bank. The length of the collapsed area was 1,300 yards, and its area about 84 acres, the depth of the depression being about 30 feet. The nearly liquid clay flowed both up and down the valley of the Maskinongé for a distance of about three-quarters of a mile in each direction, bearing with it large blocks and masses of unbroken clay. The whole movement was effected in about 3 hours, the first mass of clay detached being about 200 yards in width by 700 in length.

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* Transactions Royal Society of Canada, vol. xii, part iv, 1894, p. 63.

† Since the present paper was read a short note by the same author on the Blanche landslip has been published in the Report of the Commissioner of Colonization and Mines of Quebec for 1898, p. 131.

‡ Proceedings of the Geological Society of London, vol. iii, p. 767; also Life of Sir William Logan, p. 95.

Logan particularly notes that, except on one side, the area of the terrace-flat affected by the slip was bounded by lower land, a ridge or crest being left between the collapsed area and this lower land. This is quite similar to the fact observed in connection with the landslip on the Blanche, and is, no doubt, to be explained in the manner previously alluded to. He nowhere saw the underlying rock or other material below the clay, but is inclined to the belief that the movement may have occurred on a sloping bed of rock. If, however, my interpretation of the facts on the Blanche be correct, it seems unnecessary to assume the existence of such a sliding surface in either case, the action of gravitation upon the saturated mass of clay itself being probably sufficient to account for its flow to the lower level, the retaining bank having been broken through in the first instance.

The fifth paper of the morning session was:

RIPPLE-MARKS AND CROSS-BEDDING

BY G. K. GILBERT

Remarks were made by the President, B. K. Emerson, A. C. Spencer, C. W. Hayes, and the author. The paper is printed as pages 135–140 of this volume.

The sixth and closing paper of the session was upon

VOLCANOES OF SOUTHEASTERN RUSSIA

BY H. FIELDING REID

Doctor Reid's paper was discussed by E. O. Hovey, J. Stanley-Brown, Angelo Heilprin, L. V. Pirsson, I. C. Russell, C. D. Walcott, and the author. A short abstract is printed in Science, volume 9, January 27, 1899, page 139.

The Secretary made some announcements regarding the order of papers in the program. It was voted to organize for the afternoon session a petrographic section, before which the papers on petrology and mineralogy should be read. The proceedings of this section will be found on page 499.

The Society adjourned for lunch, and reconvened at 1.30 o'clock p m.

The first paper of the afternoon session in the general section was read by title.

FORMATION OF DIKES AND VEINS

BY N. S. SHALER

The paper is printed as pages 253–262 of this volume.

The second paper presented was:

PRECAMBRIAN FOSSILIFEROUS FORMATIONS

BY C. D. WALCOTT

The paper was discussed by J. A. Holmes, H. S. Williams, H. M. Ami, Bailey Willis, and the author. It is printed as pages 199–244 of this volume.

The discussion of the paper by Mr W. D. Johnson, postponed from Thursday (see page 479), was announced. Remarks were made by I. C. Russell, H. F. Reid, G. K. Gilbert, and the author.

The next two papers were read and discussed as one.

GLACIAL SCULPTURE IN WESTERN NEW YORK

BY G. K. GILBERT

The paper is printed as pages 121–130 of this volume.

DISLOCATION AT THIRTY-MILE POINT, NEW YORK

BY G. K. GILBERT

The paper is printed as pages 131–134 of this volume. Remarks upon the two papers by Doctor Gilbert were made by H. F. Reid, Robert Bell and the author.

The following paper was read by the senior author:

WIND DEPOSITS OF EASTERN MONTANA

BY C. W. HALL AND F. W. SARDESON

Remarks were made by J. B. Woodworth and Arthur Hollick. The paper is printed as pages 349–360 of this volume.

The next paper was:

LAKE IROQUOIS AND ITS PREDECESSORS AT TORONTO

BY A. P. COLEMAN

This paper was discussed by G. K. Gilbert and Robert Bell. It is printed as pages 165–176 of this volume.

The next paper was entitled :

THAMES RIVER TERRACES IN CONNECTICUT

BY F. P. GULLIVER

Dana classed the terraces on the sides of the drowned valley of the Thames river, Connecticut, as fluviatile deposits of the Champlain period, and thus considered that they were formed as floodplains in a greatly expanded river, their summits marking the greatest height reached by the floods from the fast melting ice-sheet. The writer has for some time considered the above hypothesis inadequate to account for the many forms assumed by the glacial waste at levels intermediate between the upper terrace and the present bed of the Thames river, particularly those typical eskers which today lie partly submerged in the waters of the estuary. Not until the recent cuts, made for the new line of the New York, New Haven and Hartford railroad in eastern Connecticut, along the east bank of the Thames river between Norwich and New London, had revealed the delta structure of these flat-topped deposits lying against the steep sides of this valley, which had been developed to adolescence before the depression of the land took place, was it possible to make out a more detailed history of the aggradation which occurred in this valley in Pleistocene time. The present paper outlines more in detail the method of this deposition.

The first question testing the flooded river hypothesis is whether these deposits form a uniform grade, rising gradually higher farther and farther upstream. Roughly, this is the fact. The terraces rise 10 to 15 feet above the river at New London and increase in height up the river until they are 90 to 100 feet above tide at Norwich. These level-topped deposits are not continuous, however, and a series of accurate levels run up the river might show that these deposits belong to more than one system and do not fall into one grade.*

At several points along the river there are typical eskers which do not rise to the level of the flat-topped deposits. These present to the eye the characteristic ridge, with steep sides and curving first to the right and then to the left, which has generally been recognized as a constructional form produced by glacial rivers at a late stage in the melting of the ice. A very good example is found about 3 miles below Norwich, on the east side of the river, opposite the little Indian village called Mohegan. The unsubmerged portion of this esker has been used by the railroad, as a part of its embankment, in crossing one of the numerous coves which resulted from the drowning of the Thames valley. The summit of this esker is in places more than 80 feet beneath the level of the gravel plain less than a mile to the north. This gravel ridge has the typical constructional esker form, as if the glacier had left it but a few weeks ago; therefore it is very difficult to conceive that a flooded river could have built a floodplain 80 feet above this deposit without obliterating its ridge-like form.

Two miles above the United States naval station there was another short esker, some 30 feet below the level of the terrace at this point on the river, which has been almost entirely removed by the engineers to fill in across one of the deep side valleys. The bottom at this place was found to be covered with very fine mud, which slid to one side when rock and gravel were piled on top, so that a great deal

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*See paper by F. B. Koons, Am. Jour. Sci., 1882, p. 425.

Figure 1.—General View of Cut at Navy Yard, looking South

Figure 2.—View at Navy Yard Cut, looking North

THAMES RIVER TERRACES IN CONNECTICUT

FIGURE 1.—NAVY YARD CUT, LOOKING EAST

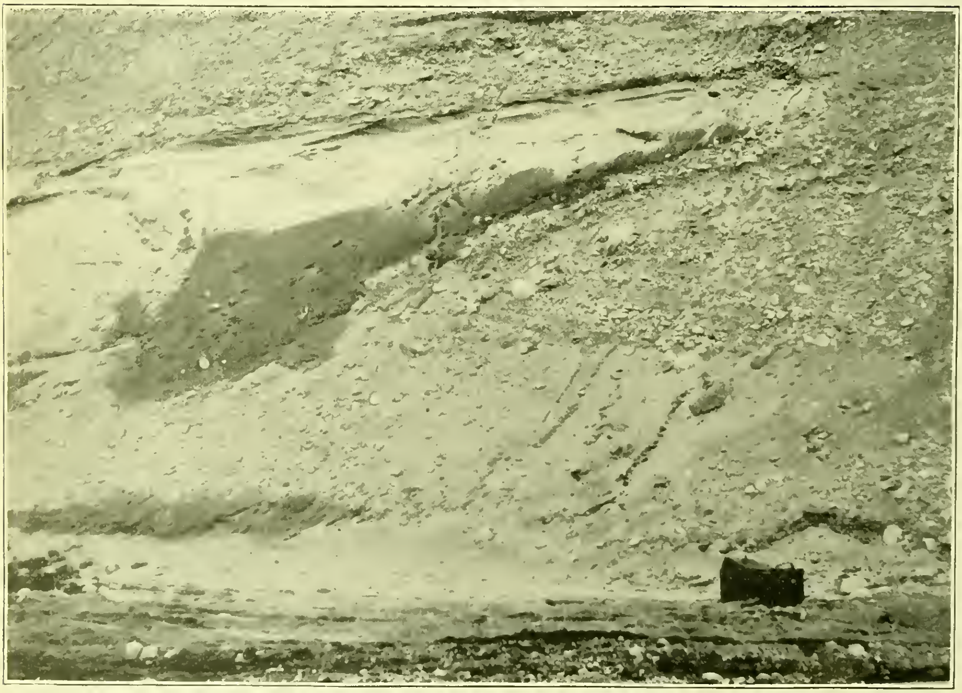

FIGURE 2.—EASTERN END OF NAVY YARD CUT, LOOKING NORTHEAST

THAMES RIVER TERRACES IN CONNECTICUT

of material was used, thus nearly obliterating the little esker that played a most important part in the history of the deposits now to be discussed.

Another difficulty with the hypothesis of a flooded river is that these terraces have numerous depressions, 10 to 15 feet in depth, which are very similar in form to kettleholes seen in sandplains in other parts of New England. These kettleholes would suggest that ice was probably present when the deposits were being built up, the sand having been washed around ice blocks.

The cuts made at the navy yard will now be considered. In order that there should be no grade crossings at this point, the road leading from the highway toward the river was cut below the level of the track. At this point, therefore, the sections were exposed much deeper into the terrace than at any other place, and the writer was so fortunate as to obtain a number of photographs of these cuts before the banks were sloped back to make the sides of the road. Four of these are here reproduced. They all show delta structure.

Figure 1 of plate 53 is a general view looking south across the cut for the road. The granite blocks lie on the level where the railroad now runs, the cut for which through the overlying deposits may be seen to the right of the cart. These overlying deposits are some 10 feet thick and made up of coarse gravel and sand in nearly horizontal layers, and are typical top-set beds of a glacial delta. At the place where the view is taken they have been removed almost entirely, leaving the fore set beds beneath them. This photograph is taken where the fore-set beds from one lobe merge into those of another lobe of the delta, the upper portions of all the layers being cut off by the succeeding top-set beds, a small portion of which had fortunately not been removed when the view was taken.

Figure 2 of plate 53 is taken in the cut looking north at southward-dipping fore-set beds, the water-laid character of which is evident from a glance at the structure as shown in the photograph. A few inches of the top-set beds are shown here also just beneath the small house.

Figure 1 of plate 54 is also taken in the cut, but looking eastward, and therefore at right angles to the general direction of water and ice flow down the valley. The connection of the top-set with the fore-set beds is here very clearly shown, in places continuous with them and in places cutting off the tops of the previously laid fore-sets. The delta character of this deposit is here unmistakable, and this is in a region where the flat-topped deposit laps up against the till-covered slopes of the sides of the valley in a manner strongly to suggest the terrace origin.

Figure 2, plate 54, is taken at the extreme eastern end of the cut and shows the better stratified deposits overlying the less stratified deposits at the edge of the delta-terrace, where the stratified drift ends and the unstratified drift begins. Less than 20 feet east of where this photograph is taken, there is unmistakable till. Along the margin of the terrace at this point the sections show, mixed with the less stratified water-worn material, some more angular rock waste that is morainal in character. This point would thus appear to have been an ice-margin at a time immediately preceding that of delta-building. This deposit would indicate that there was a tongue of ice extending down the valley with its margin at this point when the water from the melting glacier came out farther down the valley, perhaps at New London; and that a little later, when the tongue did not quite fill the valley, a glacial delta was built at this point, filling in completely the space between the ice and the valley side. The stream which supplied this waste was some 2 miles above the navy yard, as is indicated by the esker mentioned above. For the method of building up of this deposit the reader is referred to Professor Russell's account of the Malaspina glacier.*

There are no lobes pointing downstream in the direction of ice and water movement, as one would be led to expect from a study of New England sandplains; † but the position of all the eskers at the side of the valley indicates that the ice was in the center of the valley, and if the waste was sufficient to fill in all the space between the ice and the valley sides, as the deposit at the navy yard seems to show, there would have been no chance for the formation of lobes.

Although there are no lobes at the navy yard, the writer found several places along the river where tributaries enter, which were not completely filled in by waste from the ice-tongue to valley margin, and here the typical lobe form was found. One of the best examples is seen at Poquetannock cove, on the east side of the river, where there is a large amount of washed drift, on the eastern margin of which there are a number of well developed lobes which point eastward, as if formed by streams flowing from an ice tongue in the center of the river.

The ice-contact slope or moraine terrace is the steep slope of these flat-topped deposits which now faces the Thames river, if the above outlined delta hypothesis is to replace the floodplain hypothesis. It would then follow that the washed drift in this valley had been very slightly altered in form since the last retreat of the ice. In all points where man has not materially changed the aspect of these terrace slopes the form seems to the writer to be better explained as an ice-contact slope than in any other way. In a number of places boulders are found on these steep slopes facing the river, the position of which is easy to explain if we conceive a contiguous ice-margin from which they might have fallen; but it is impossible to see how they could stand where they do if the edge of this deposit is the result of erosion.

There are many other interesting features about these Thames River deposits, such as the rock hill at Montville, around which the ice flowed in two streams, forming two sets of terraces, the sandplain at Montville, or the extensive plains at Norwich, which should all be described in making out the history of this region in the way it has been done for Narragansett bay.‡ The field survey for this work has not been completed yet, so the details of the history of these deposits is not here given. Enough facts have been mentioned to show that these delta-terraces were formed when the ice was present in the drowned valley, and the suggestion is made that the structure of other so-called glacial terraces be examined to see if they were not similarly formed. There are undoubted fluviatile terraces,§ and these should be discriminated from such delta-terraces as are here described.

A most interesting question is the water level shown by these delta deposits. It may be the sealevel, in which case a tilting of the land is shown by these Thames River deposits, the greater elevation being inland; it may be a series of lakes, as has been suggested by Mr Robert Chalmers, ‖ or it may be that there was a blocking up of the valley at New London by ice or rock waste or both, and that as the ice melted first from the sides of the valley it left water bodies on each side of an

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* Nat. Geog. Mag., vol. iii, 1891, pp. 106–109.

† W. M. Davis, in Bull. Geol. Soc. Am., vol. i, 188–, pp. 195–202. F. P. Gulliver, in Chicago Jour. of Geol., vol. i, 1893, pp. 803–812.

‡ J. B. Woodworth, in Am. Geologist, vol. xviii, 1896, pp. 150–168.

§ See paper by R. E. Dodge, in Proc. Boston Soc. Nat. Hist., vol. xxvi, 1894, pp. 257–273.

‖ Ann. Rep. Geol. and Nat. Hist. Survey of Canada, vol. iv, 1888, p. 61.

ice-tongue, and that the streams from this tongue built out their deltas into this water on either side. From the facts known at present it is not possible to say just which condition prevailed in the Thames valley.

Remarks on Mr Gulliver's paper were made by J. B. Woodworth.

In the absence of the author the following paper was read in abstract by Robert Bell:

GOLD-BEARING VEINS OF BOG BAY, LAKE OF THE WOODS

BY PETER MC KELLAR

[*Abstract*]

Many auriferous veins have been prospected and a considerable number mined in this part of the gold region of western Ontario. Three of the companies operating there, namely, the Tycoon, Toronto and Western, and the Mikado, are working on veins cutting the Bog Bay granite mass. The peculiar feature of these veins is the smallness of the quartz fissures compared with the total size of the ore bodies, and it is this characteristic that the present paper is intended to explain.

The geology of the whole district from lake Superior to the west side of lake of the Woods, with a breadth of over 300 miles, has been investigated and the results published in detail by the Geological Survey of Canada.

Doctor Bell commenced the real work in the Thunder Bay district in 1869, and in the Wabigoon and Lake of the Woods regions in 1881, and made the first geological maps of these territories. He showed that the rocks of this great area were essentially Laurentian and Huronian, the gneisses and the principal acid eruptives being classed with the former, while the green schists in general and the basic eruptives were provisionally included in the latter system. In many places both groups of rocks were shown to be intersected by felsitic and greenstone dikes and numerous fissure veins, many of which are now proving to be auriferous.

The author described, illustrating by diagrams, the three mines above mentioned and showed that small quartz veins cutting the granite were accompanied on one or both sides by a workable thickness of an auriferous mineral to which he gave the tentative name mikadoite.

The quartz veins are frequently so small as to be traced with difficulty for any considerable distance on the surface, yet when opened up by mining they generally show a breadth of 2 to 6 feet or more of gold-bearing ore, consisting mostly of this mineral, which resembles light greenish-gray serpentine, but has a coarse granular fracture like the granite itself. It passes by insensible degrees into quartz, but when pure it is easily distinguished by its softness and the unctuous character of its powder.

Iron pyrites in very fine grains is disseminated through it to the extent of one-half to three per cent or more, and this vein-mineral may be identical with a similar one, also characterized by fine-grained iron pyrites, which forms parts of some of the gold-bearing veins of the Ural mountains. The weathered surface of the mikadoite resembles that of the adjoining granite, and the outcroppings of these peculiar veins would be passed over as unworthy of notice, even by experienced prospectors, unless their attention had been previously called to their character and importance.

Even when veins of this nature contain but little gold at the surface they are generally found to be richer in depth, and from their supposed mode of formation the author attempts to give a rational explanation of this circumstance.

They are evidently true fissures, as indicated by the faulting which may be seen along some of them, and also from the fact that they intersect alike both the massive and the stratified rocks. The mikadoite spreads out irregularly on either side of the quartz sheet which accompanies it and forms, as it were, the backbone of the vein. The latter may carry small quantities of the sulphides of copper, lead, zinc, and more rarely bismuth, but these minerals are scarcer in the mikadoite, in which the fine grained pyrite above mentioned is the prevailing sulphide.

Many of the felsite and greenstone dikes of Bog Bay district have been found by assay to be auriferous and a few of them are being worked for gold with promising results.

It seems highly probable to the author that the gold was derived from heated vapors and solutions which ascended through the fissures from great depths, presumably from the vicinity of the magmas—the source of the felsites and greenstones.

The felsite dikes are generally present near the veins and are usually more or less charged with the fine grained sulphide of iron that almost invariably accompanies the gold in the veins. Their auriferous character is more marked when they are close to the quartz veins. The felsite in many places loses the crystalline texture and passes into phonolite with the usual metallic ring. It is probable that this rock may have some connection with the occurrence of the gold here, as the phonolites of the famous Cripple Creek district of Colorado are admitted to have in that region. In a somewhat similar way the trappean eruptions of the Keweenaw district are believed to be connected with the presence of native copper there. For these reasons the auriferous veins under consideration may be expected to continue productive to a considerable depth, and to improve rather than the reverse at lower depths.

In regard to the manner in which these veins were formed, the author, after much study and observation, reaches the conclusion that during the movements which caused these rents a sufficient pressure was exerted to prevent a separation of the walls so as to leave openings for the reception of the vein matter; hence the openings now filled with gangue must have been subsequently created. The heated solutions that would be certain to percolate through these fissures would dissolve the silica out of the wall-rocks and deposit it as vein-quartz, while the crushed rock adjoining the fissures would be metamorphosed in the manner described by Professor C. R. Van Hise in his admirable paper "Metamorphism of Rocks and Rock-flowage." Referring to the same subject, Dr M. E. Wadsworth, states in his pamphlet "The Lake Superior Copper Deposits," issued in 1891, that "one of the latest phases of the formation of deposits of value has been the filling in of fissures by the water-deposited quartz and other vein materials, or, in case no crack nor fissure existed, by the removal of the country rocks along certain lines and their replacement by vein matter."

Attention is called to the great difference in character between the gold-bearing fissure veins of Archean time and those of later age, such as the silver-bearing veins of the Thunder Bay district.

The latter show well defined walls with brecciated extraneous matter frequently inclosed in the quartz or sparry matrix, while the adjacent rocks are but slightly, if at all, laminated or metamorphosed. The newer or open-fissure veins of the later formations are sometimes continued with the same characters into the underlying Archean rocks. On the other hand the veins in the Archean rocks of more ancient origin rarely show two well defined walls, they seldom contain extraneous brecciated matter, and the adjacent country rock is generally laminated and highly metamorphosed. The laminated portions are, in many instances, an important factor in the gold veins of the latter class, as shown by those of Bog bay.

The author believes that the auriferous veins of this western Ontario district were all formed in Archean time, because after many years of exploration he knows of no place around lake Superior where such veins penetrate the later formations. Such veins occur in the Archean areas on both sides of this lake, as at Jackfish bay, at Schreiber and around Shebandowan lake on the north side, and again at the Ropes gold mine near Ishpeming on the south side, but nowhere in the later rocks which lie between the last mentioned locality and the others.

The metalliferous veins formed during the Archean period have, therefore, a different set of characters from those which originated in subsequent times, when the crust of the earth had become thicker and colder. In the early age of the globe to which the Archean rocks belong, the crust must have been thinner and weaker, the heat greater, the gaseous elements more powerful, and the shrinkage of the crust more rapid and intense than in later times. Therefore we might expect to find the rock formations greatly fractured and the sides of the rents ground and laminated to a greater extent than in veins of later date. Although veins of the open spaced fissure kind do occur in some places in these ancient rocks, still the majority of their veins are of the other variety, in which the space for the reception of the gangue was created by solvents circulating through the crushed material along the fractures. In the latter case, the size of the vein proper is not a fair measure for comparing the strength, value, or continuity of the ore-body with that of an ordinary fissure vein occurring in newer formations. The lamination of the walls of the veins formed in Archean time may be taken as a guide for distinguishing them from those of the other class. The author is of the opinion that mining men and experts in general will be mistaken if they look for the general characteristics of open-fissure veins in judging of those of the western gold fields of Ontario.

Gold-bearing veins of the class here described are not confined to the Bog Bay district. Similar ones, accompanied by mikadoite, cut granite rocks in the vicinity of Sawbill lake on the Seine river. It is supposed that the granite of this locality was erupted about the same time as that of Bog bay and from an analogous magma. Dikes of felsite and diorite, like those of the latter locality, intersect this granite. The Hammond Reef mine of the Sawbill region is situated upon a belt from 100 to 500 feet in width of parallel quartz and mikadoite veins having characters similar to those of Bog bay. In fact, these characteristics, to a more or less extent, prevail throughout these extensive Ontario western gold fields.

The following papers were all read by title:

ROCKY MOUNTAINS OF MONTANA

BY BAILEY WILLIS

ORIGIN OF SOME ARCHEAN CONGLOMERATES

BY A. E. BARLOW

GEOLOGY OF THE CRYSTALLINE ROCKS OF MANHATTAN ISLAND AND VICINITY

BY FREDERICK J. H. MERRILL

ORIGIN OF THE HIGHLAND GORGE OF THE HUDSON RIVER

BY FREDERICK J. H. MERRILL

[*Abstract*]

The object of this paper is to call attention to some facts of geologic structure which have had a very important influence on the course of the Hudson river and the location of its gorge through the pre-Cambrian highlands of Putnam and Orange counties, New York.

This gorge has been for many years a subject of interest to geologists, and various theories have been advanced concerning its origin. The most prominent of these was that the river had followed an old fault line, erosion having been guided by a line of displacement.

Careful examination of the gorge and the adjacent territory shows that no displacement has occurred and that no fault is there, but stratigraphic study of the region has recently brought to light some facts which aid materially in assigning a reason for the course taken by the river through the area of crystalline rocks under consideration.

The central portion of the highland gorge, about 7 miles in length, extending from Cold Spring to Anthonys Nose, has a direction about north 30 degrees east, following the general strike of the gneisses which form its sides. These rocks are very distinct in character from the massive granites which form the highland mountains, being quite schistose in structure, and include, at a number of points along the east shore of the river, small areas of highly crystalline limestone. The river in this part of the gorge is about half a mile wide. All evidence of the character of the rocks which form its bottom is wanting, and we are obliged to go northward along the line of strike to determine their probable character. As may be seen from an inspection of the West Point topographic sheet, from Cold Spring northeastward extends a continuation of the valley occupied by the river, which, about 8 miles from Cold Spring, opens into the Paleozoic plain of southern Dutchess county. Through this valley the Trenton-Calciferous limestone of the latter region can be traced for some distance southward in a closely pressed synclinal fold, the pale blue, fine-grained limestone of Fishkill being succeeded farther southwest, near Cold Spring, by a crystalline limestone which is apparently, in stratigraphic continuity with the former, but which, by metamorphism, has become vastly changed in its condition.

This crystalline limestone is inclosed by gneisses similar in character to those

bordering the river between West Point and Fort Montgomery. The inference from stratigraphic continuity is therefore that the Hudson river from West Point to Fort Montgomery follows a synclinal valley, along the bottom of which is a narrow belt of limestone bordered on either side by schistose rocks which have been more susceptible to erosion than the massive granites of the Highland mountains which form the walls of the valley. This feature, which is characteristic of the central portion of the gorge, does not exist at its northern and southern extremities. Each of these is much shorter than the central part and has a trend quite oblique to it.

An examination of the terminal portions shows that their determining cause is not a syncline of softer gneisses and limestone, but a synclinal cross-folding of the granite, which is characteristic of the crystalline area of southeastern New York and has everywhere an important influence on its drainage. This cross-folding is usually attended by fracture, and although we cannot positively assert that the latter has occurred at the two points mentioned, it is highly probable that the work of erosion has been aided in this way.

IOWAN DRIFT

BY SAMUEL CALVIN

The paper is printed as pages 107–120 of this volume.

LOESS DEPOSITS OF MONTANA

BY N. S. SHALER

The paper is printed as pages 245–252 of this volume.

SPACING OF RIVERS WITH REFERENCE TO HYPOTHESIS OF BASELEVELING

BY N. S. SHALER

The paper is printed as pages 263–276 of this volume.

The general session was then transferred to the room where the Petrographic Section was yet in progress. The work in this special section was as follows:

PROCEEDINGS OF THE PETROGRAPHIC SECTION

This temporary section was convened on Friday, at 2 o'clock p m, in the geological lecture-room of Schermerhorn Hall. Vice-President Emerson was made chairman and J. F. Kemp secretary. Six papers were read before the section, the first of which was

DIFFERENCE IN BATHOLITHIC GRANITES ACCORDING TO DEPTH OF EROSION

BY B. K. EMERSON

[*Abstract*]

It was stated that the Quincy granite band with the associated quartz-porphyries, rhyolitic breccias, and granophyrs extended south beneath the Carboniferous to

South Greenwich, south of Providence, Rhode Island, and a quartz-porphyry and granite containing blue quartz were especially described. South of the Boston area these granites do not alter the Cambrian schists and do not absorb any material from them. Several other bands extending across Worcester county were contrasted with the Quincy band in the following particulars: They are often coarsely porphyritic, while the Quincy granites are not. They are microcline granites. The Quincy granites are orthoclase granites. They contain biotite or biotite and muscovite instead of biotite and hornblende or glaucophane.

These granite batholites are also contrasted with the Quincy rock in having a broad peripheral layer which has all the peculiarities of pegmatite in some cases, and grades into black albitic granites or even quartz-diorites.

These differences are largely due to the fact that these rocks have fused much of the surrounding schist into their composition, and this was proved by finding characteristic inclusions of the schist in great numbers and of every size in the granite, and also by tracing these inclusions into smaller and smaller filaments until they faded from sight, and finding with the microscope far beyond this point in the fresh granite clear traces of the schists. When the schist contains pyrite, garnet, fibrolite, cordierite, or graphite, the granite becomes more ferruginous and garnetiferous. The amber coarse fibrolite of the schist appears dissolved and recrystallized as a white, silky bucholzite or fazer-kiesel in the granite, and the graphite scales are inclosed in all the constituents of the granite over many square miles.

Over the whole surface of the great Hubbardston batholite of perfect, coarse porphyritic granite 32 miles long and 6 miles wide it was possible to map the areas once occupied by the different schists, which formerly mantled over the granite mass by means of the indestructible constituents of the former schists; by the portions which had melted into the mass of the granite; by the filaments still remaining unabsorbed, and by the different aspect of the granite, dependent largely on the great increment of iron. Using especially the first two criteria, this double mapping of the region will be carried out in the sheets being prepared for the United States Geological Survey.

The region extending for several miles south from mount Wachusett and that north and south of Brookfield in the Hubbardston batholite furnish abundant exposures for the study of the phenomena here described.

The paper was discussed by Whitman Cross, M. E. Wadsworth, J. F. Kemp, and the author. Two papers by Kemp followed:

METAMORPHOSED BASIC DIKES IN THE MANHATTAN SCHISTS

BY J. F. KEMP

Remarks were made by M. E. Wadsworth.

GRANITES OF SOUTHERN RHODE ISLAND AND CONNECTICUT, WITH OBSERVATIONS ON ATLANTIC COAST GRANITES IN GENERAL

BY J. F. KEMP

Remarks were made by J. E. Wolff. The paper is printed as pages 361–382 of this volume.

The next paper was

AUGITE-SYENITE GNEISS NEAR LOON LAKE, NEW YORK

BY H. P. CUSHING

Remarks were made by H. S. Washington, J. F. Kemp, M. E. Wadsworth, and N. H. Winchell. The paper is printed as pages 177–192 of this volume. It was followed by

PHENOCRYSTS OF INTRUSIVE IGNEOUS ROCKS

BY L. V. PIRSSON

Remarks were made by J. P. Iddings and Whitman Cross. The last paper was

MICA DEPOSITS OF THE UNITED STATES

BY J. A. HOLMES

[*Abstract*]

The deposits of commercial mica in the United States, though widely distributed, are limited to a few districts. They have been worked to some extent along the Appalachian system of mountains in New Hampshire, Virginia, North Carolina, the Black Hills region of South Dakota, the Cribbensville district of northern New Mexico, and western Idaho.

Additional deposits of promise have been found and developed on a small scale in the Appalachian region in Maine, Maryland, South Carolina, Georgia, and Alabama, and in California, Wyoming, Nevada, and other portions of New Mexico. As to the geologic occurrence of these deposits it may be said that as far as examined in the United States they are all found in pegmatite "veins" or dikes; and these pegmatite dikes occur in schistose and gneissic rocks which are usually classed as Archean in age, but some of them are evidently more recent. The dikes yielding the best and largest quantities of mica are found in the hornblende and micaceous gneisses and schists, and are in places parallel to but generally breaking across the schistosity of these rocks at varying angles.

Pegmatite dikes, as is well known, vary in thickness from a few inches to more than 250 feet, and can be traced for distances varying from a few feet in the smaller ones to sometimes several miles in the larger ones. They are generally quite irregular and have arms branching out in almost every direction. Many are vertical, while others are horizontal; most of them vary considerably in this respect.

In character the pegmatite may be called an exceedingly coarse granite, consisting mainly of quartz and feldspar, in equal or variable proportions, and muscovite mica. In some places the quartz and feldspar are somewhat uniformly distributed through the pegmatite mass, while in other cases the two are fairly well separated, the feldspar sometimes crystallized out into masses more than a ton in weight. In addition to these three common minerals, there occur in these dikes a large number of accessory minerals with varying degrees of rarity. The dikes in certain localities sometimes contain a considerable number of these min-

erals—20 or more species being occasionally observed in a single dike—and in other regions few of them are to be found. Thus in the dikes of Mitchell and Yancey counties, North Carolina, these accessory minerals are both numerous and varied, 47 or more being enumerated by Pratt, of which the following most common 20 species may be named, approximately in the order of their abundance: kaolin, almandite, and andradite (garnets), tourmaline, beryl, apatite, epidote, biotite, microcline, orthoclase, allanite (?), uraninite, gummite, autunite, columbite, samarskite, zosite (var. thulite), pyrite, magnetite, menaccanite. But in Macon county, over 100 miles southwest, accessory minerals are exceedingly rare.

In the Black Hills region of South Dakota these mica dikes contain a number of accessory minerals, but not in such variety as has been found in the North Carolina region. The following species were observed there by the writer: tourmaline (mostly black), microcline, albite—oligoclase (sparingly well crystallized), quartz (massive—pink or rose), muscovite, lepidolite, biotite, epidote, garnet (rare), columbite, wolframite, spodumene (large rough crystals), apatite (rare), menaccanite, cassiterite. Two additional species, triphylite and leucopyrite, have been reported by Blake. In the Cribbensville district, New Mexico, there are but few accessory minerals and these are rare.

The country rock immediately adjacent to these pegmatite dikes have as a rule undergone but slight changes. Frequently they are somewhat impregnated with the quartz and feldspar of the dike, these materials being sufficiently abundant in some cases to give the walls of the dike for several inches from the contact a grayish or whitish appearance, although the country rock may have been a darker color. The alteration as a rule does not extend out more than one or two feet from the dike, generally not more than a few inches. After this perhaps the most common feature is what may be called the tourmalinization of the country rock to a distance of from a few inches to one or more feet distant from the rock, the tourmaline in small grains or crystals being at times quite abundant next the dike and gradually diminishing as this distance increases. As a rule, the crystals ("blocks" or "books") of commercial mica need not be looked for in the dikes or veins under two feet in diameter, but there are cases in which crystals two by two and one-half feet in diameter have been found in the dikes, the width of which was scarcely greater than these figures. On the other hand, in case of some of the larger dikes no mica whatever of commercial value has been found, as, for example, the large dike being mined for kaolin by the Harris Clay company, near Webster, North Carolina.

As to the distribution of mica in the dike, it may be said that generally these crystals are scattered irregularly through the matrix of quartz and feldspar, and in mining operations a large amount of useless material has to be blasted down and removed from the mine in order to secure the commercial product. In other cases, however, the crystals of mica occur in the outer part of the dike near the wall rock, and in such cases the mica "lead" may be more easily followed. In some cases the mica constitutes as high as 10 per cent of the total mass of the dike, but in the majority of cases it will prove to be less than one per cent of the total, and in many of the largest pegmatite dikes, as stated above, no commercial mica is found, the mica present being in small scales and crystals, the largest diameter of which would rarely exceed two inches. Of the mica taken from the dike in ordinary mining operations, usually less than 10 per cent, and sometimes less than 2 per cent, has a commercial value as sheet mica, the remainder being either thrown away as waste material or pulverized for commercial uses.

The age of these dikes in different parts of the country may be said to vary considerably. In crystalline rocks exposed in the lower part of the Grand canyon of the Colorado in northern Arizona, the dikes break up through the granitic rocks, but come unconformable against the base of the Algonkin series there, and are consequently pre-Algonkin in age. All of the dikes observed in the Rocky Mountain region have been to a greater or less degree involved in the schistosity and other structural modifications of the crystalline rocks, and consequently were probably formed during the earlier stages of the uplift of these mountains. In the Appalachian region these dikes are not in most cases extensively involved in the schistose structures of the rocks, but in some cases they have undergone considerable changes in connection with the production of these structures, and the conditions surrounding these dikes seem to indicate that they were formed during the later stages of the uplift of this mountain region, though in some cases the smaller dikes are involved in folds quite similar in general character to those typical of the Appalachian structure. In cases of these larger Appalachian dikes, however, the crystalline character is such as to indicate few or no great pressure changes, and to suggest the association of such dikes with the later development of this mountain region.

Occasionally in the Black hills and in New Mexico, and less frequently in the Appalachian region, the sheets of mica have themselves been folded under pressure, but as a rule they show little such distortion, having been, like the coarse feldspar and quartz of the dike, but little modified in connection with the mountain uplifting. These blocks of mica, however, frequently have their commercial value in large measure destroyed by the reproduction of what is called "ruled" or "ribbon" mica, the sheets of mica being cut into narrow strips with parallel edges, the line of ruling or cutting appearing in all cases to be parallel to certain axes of crystallization; but the cause of this "ruling" and the conditions under which it has been produced are not yet well understood.

During the reading of Professor Holmes' paper the Fellows in attendance at the meeting gathered in the Petrographic Section, which was then regarded as the general Society meeting, with Vice-President Emerson in the chair.

The scientific work was declared completed.

Mr J. S. Diller presented a resolution of thanks to the President and Trustees of Columbia University for the welcome to the University and the use of the rooms and facilities, to the resident Fellows who had served as a local Committee of Arrangements, and to Mr George F. Kunz for his labors in connection with the annual dinner.

The Society then adjourned.

Register of the New York Meeting, 1898*

The following Fellows were in attendance at the meeting:

F. D. Adams.
H. M. Ami.
Florence Bascom.
Robert Bell.
S. W. Beyer.
A. S. Bickmore.
J. M. Clarke.
A. P. Coleman.
F. W. Cragin.
W. O. Crosby.
Whitman Cross.
H. P. Cushing.
N. H. Darton.
G. M. Dawson.
J. S. Diller.
E. V. d'Invilliers.
R. E. Dodge.
C. R. Eastman.
B. K. Emerson.
S. F. Emmons.
H. L. Fairchild.
H. T. Fuller.
G. K. Gilbert.
A. C. Gill.
L. S. Griswold.
F. P. Gulliver.
C. W. Hall.
C. W. Hayes.
Angelo Heilprin.
Arthur Hollick.
J. A. Holmes.
T. C. Hopkins.
E. O. Hovey.
E. E. Howell.
J. P. Iddings.
W. D. Johnson.
A. A. Julien.
J. F. Kemp.
H. B. Kümmell.
G. F. Kunz.
W J McGee.
A. M. Miller.
H. F. Osborn.
Charles Palache.
L. V. Pirsson.
J. W. Powell.
C. S. Prosser.
F. L. Ransome.
H. F. Reid.
Heinrich Ries.
I. C. Russell.
H. M. Seely.
N. S. Shaler.
E. A. Smith.
G. O. Smith.
J. C. Smock.
A. C. Spencer.
Joseph Stanley-Brown.
J. J. Stevenson.
J. A. Taff.
H. W. Turner.
J. B. Tyrrell.
A. W. Vogdes.
M. E. Wadsworth.
C. D. Walcott.
H. S. Washington.
David White.
I. C. White.
H. S. Williams.
Bailey Willis.
N. H. Winchell.
J. E. Wolff.
R. S. Woodward.
J. B. Woodworth.
A. A. Wright.
W. S. Yeates.

Fellow-elect: T. G. White.

Total attendance, 77.

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* During some part of the last day of the meeting the Society was pleased to have in attendance as a visitor Dr Oliver P. Hubbard, one of the surviving members of the Association of American Geologists and Naturalists, 1840–1847.

OFFICERS AND FELLOWS OF THE GEOLOGICAL SOCIETY OF AMERICA

OFFICERS FOR 1899

President

B. K. Emerson, Amherst, Mass.

Vice-Presidents

G. M. Dawson, Ottawa, Canada
C. D. Walcott, Washington, D. C.

Secretary

H. L. Fairchild, Rochester, N. Y.

Treasurer

I. C. White, Morgantown, W. Va.

Editor

J. Stanley-Brown, Washington, D. C.

Librarian

H. P. Cushing, Cleveland, O.

Councillors

(Term expires 1899)

J. S. Diller, Washington, D. C.
W. B. Scott, Princeton, N. J.

(Term expires 1900)

Robert Bell, Ottawa, Canada
M. E. Wadsworth, Houghton, Mich.

(Term expires 1901)

W. M. Davis, Cambridge, Mass.
J. A. Holmes, Chapel Hill, N. C.

FELLOWS, DECEMBER, 1899

*Indicates Original Fellow (see article III of Constitution)

Cleveland Abbe, Jr., Ph. D., Rock Hill, S. C.; Professor in Winthrop Normal College of South Carolina. August, 1899.

Frank Dawson Adams, Ph. D., Montreal Canada; Professor of Geology in McGill University. December, 1889.

José Guadalupe Aguilera, Esquela N. de Ingeneiros, City of Mexico, Mexico; Director del Instituto Geologico de Mexico. August, 1896.

Truman H. Aldrich, M. E., Birmingham, Ala. May, 1889.

Henry M. Ami, A. M., Geological Survey Office, Ottawa, Canada; Assistant Paleontologist on Geological and Natural History Survey of Canada. December, 1889.

Philip Argall, 821 Equitable Building, Denver, Colo.; Mining Eng. August, 1896.

George Hall Ashley, M. E., A. M., Ph. D., 207 East Fifteenth St., Indianapolis, Ind.; Assistant Geologist, Indiana Geological Survey. August, 1896.

Harry Foster Bain, M. S., Des Moines, Iowa; Assistant Geologist, Iowa Geological Survey. December, 1895.

Rufus Mather Bagg, A. B., Ph. D., Colorado College, Colorado Springs, Colo. December, 1896.

S. Prentiss Baldwin, 1345 Euclid Ave., Cleveland, Ohio. August, 1895.

Erwin Hinckley Barbour, A. B., Ph. D., Lincoln, Neb.; Professor of Geology, University of Nebraska, and Acting State Geologist. December, 1896.

George H. Barton, B. S., Boston, Mass.; Instructor in Geology in Massachusetts Institute of Technology. August, 1890.

Florence Bascom, A. M., B. S., Ph. D., Bryn Mawr, Pa.; Instructor in Geology, Petrography, and Mineralogy in Bryn Mawr College. August, 1894.

William S. Bayley, Ph. D., Waterville, Maine; Professor of Geology in Colby University. December, 1888.

*George F. Becker, Ph. D., Washington, D. C.; U. S. Geological Survey.

Charles E. Beecher, Ph. D., Yale University, New Haven, Conn. May, 1889.

Robert Bell, C. E., M. D., LL. D., Ottawa, Canada; Assistant Director of the Geological and Natural History Survey of Canada. May, 1889.

Samuel Walker Beyer, B. Sc., Ph. D., Ames, Iowa; Assistant Professor in Geology, Iowa Agricultural College. December, 1896.

Albert S. Bickmore, Ph. D., American Museum of Natural History, New York; Professor in charge Department of Public Instruction. December, 1889.

*John C. Branner, Ph. D., Stanford University, Cal.; Professor of Geology in Leland Stanford Jr. University.

Albert Perry Brigham, A. B., A. M., Hamilton, N. Y.; Professor of Geology and Natural History, Colgate University. December, 1893.

*Garland C. Broadhead, Columbia, Mo.; Professor of Geology in the University of Missouri.

Alfred Hulse Brooks, B. S., Washington, D. C.; Assistant Geologist, U. S. Geological Survey, August, 1899.

*Samuel Calvin, Iowa City, Iowa; Professor of Geology and Zoology in the State University of Iowa. State Geologist.

Henry Donald Campbell, Ph. D., Lexington, Va.; Professor of Geology and Biology in Washington and Lee University. May, 1889.

Marius R. Campbell, U. S. Geological Survey, Washington, D. C. August, 1892.

Franklin R. Carpenter, Ph. D., Deadwood, South Dakota; Superintendent Deadwood and Delaware Smelting Company. May, 1889.

Robert Chalmers, Geological Survey Office, Ottawa, Canada; Geologist on Geological and Natural History Survey of Canada. May, 1889.

*T. C. Chamberlin, LL. D., Chicago, Ill.; Head Professor of Geology, University of Chicago.

Clarence Raymond Claghorn, B. S., M. E., Vintondale, Pa. August, 1891.

*William Bullock Clark, Ph. D., Baltimore, Md.; Professor of Geology in Johns Hopkins University; State Geologist.

John Mason Clarke, A. M., Albany, N. Y.; State Paleontologist. December, 1897.

*Edward W. Claypole, D. Sc., Pasadena, Cal.

J. Morgan Clements, B. A., Ph. D., Madison, Wis.; Assistant Professor of Geology in University of Wisconsin. December, 1894.

Collier Cobb, A. B., A. M., Chapel Hill, N. C.; Professor of Geology in University of North Carolina. December, 1894.

Arthur P. Coleman, Ph. D., Toronto, Canada; Professor of Geology, Toronto University, and Geologist of Bureau of Mines of Ontario. December, 1896.

George L. Collie, Ph. D., Beloit, Wis.; Professor of Geology in Beloit College. December, 1897.

*Theodore B. Comstock, Los Angeles, Cal.; Mining Engineer.

*Francis W. Cragin, B. S., Colorado Springs, Colo.; Professor of Geology and Natural History in Colorado College.

*Albert R. Crandall, A. M., Alfred, N. Y.

Alja Robinson Crook, A. B., Evanston, Ill.; Professor of Mineralogy and Petrography in Northwestern University. December, 1898.

*William O. Crosby, B. S., Boston Society of Natural History, Boston, Mass.; Asst. Prof. of Mineralogy and Lithology in Massachusetts Inst. of Technology.

Whitman Cross, Ph. D., U. S. Geological Survey, Washington, D. C. May, 1889.

Garry E. Culver, A. M., 1104 Wisconsin St., Stevens Point, Wis. December, 1891.

*Henry P. Cushing, M. S., Adelbert College, Cleveland, Ohio; Professor of Geology, Western Reserve University.

T. Nelson Dale, Williamstown, Mass.; Geologist, U. S. Geological Survey; Instructor in Geology, Williams College. December, 1890.

*Nelson H. Darton, United States Geological Survey, Washington, D. C.

*William M. Davis, Cambridge, Mass.; Professor of Physical Geography in Harvard University.

George M. Dawson, D. Sc., A. R. S. M., Geological Survey Office, Ottawa, Canada; Director of Geological and Natural History Survey of Canada. May, 1889.

David T. Day, A. B., Ph. D., U. S. Geol. Survey, Washington, D. C. August, 1891.

Orville A. Derby, M. S., Sao Paulo, Brazil; Director of the Geographical and Geological Survey of the Province of Sao Paulo, Brazil. December, 1890.

*Joseph S. Diller, B. S., United States Geological Survey, Washington, D. C.

Edward V. d'Invilliers, E. M., 711 Walnut St., Philadelphia, Pa., Dec., 1888.

Richard E. Dodge, A. M., Teachers' College, West 120th St., New York city; Professor of Geography in the Teachers' College. August, 1897.

Noah Fields Drake, Ph. D., Tientsin, China; Professor of Geology in Imperial Tientsin University. December, 1898.

Charles R. Dryer, M. A., M. D., Terre Haute, Ind.; Professor of Geography, Indiana State Normal School. August, 1897.

* Edwin T. Dumble, Austin, Texas; State Geologist.

Clarence E. Dutton, Major, U. S. A., Ordnance Department, Washington, D. C. August, 1891.

* William B. Dwight, M. A., Ph. B., Poughkeepsie, N. Y.; Professor of Natural History in Vassar College.

Charles R. Eastman, A. M., Ph. D., Cambridge, Mass.; Assistant in Paleontology in Harvard University. December, 1895.

* George H. Eldridge, A. B., United States Geological Survey, Washington, D. C.

Arthur H. Elftman, Ph. D., Grand Marais, Minn. December, 1898.

Robert W. Ells, LL. D., Geological Survey Office, Ottawa, Canada; Geologist on Geological and Natural History Survey of Canada. December, 1888.

* Benjamin K. Emerson, Ph. D., Amherst, Mass.; Professor in Amherst College.

* Samuel F. Emmons, A. M., E. M., U. S. Geological Survey, Washington, D. C.

John Eyerman, F. Z. S., Oakhurst, Easton, Pa. August, 1891.

Harold W. Fairbanks, B. S., Berkeley, Cal.; Geologist State Mining Bureau. August, 1892.

* Herman L. Fairchild, B. S., Rochester, N. Y.; Professor of Geology in University of Rochester.

J. C. Fales, Danville, Kentucky; Professor in Centre College. December, 1888.

Oliver C. Farrington, Ph. D., Chicago, Ill.; In charge of Department of Geology, Field Columbian Museum. December, 1895.

William M. Fontaine, A. M., University of Virginia, Va.; Professor of Natural History and Geology in University of Virginia. December, 1888.

* Persifor Frazer, D. Sc., 1042 Drexel Building, Philadelphia, Pa.; Professor of Chemistry in Franklin Institute.

* Homer T. Fuller, Ph. D., Springfield, Mo.; President of Drury College.

Myron Leslie Fuller, S. B., Boston, Mass.: Instructor in Geology, Massachusetts Institute of Technology. December, 1898.

Henry Stewart Gane, A. B., Ph. D., 425 La Salle Ave., Chicago, Ill. Dec., 1896.

Henry Gannett, S. B., A. Met. B., U. S. Geological Survey, Washington, D. C. December, 1891.

* Grove K. Gilbert, A. M., LL. D., U. S. Geological Survey, Washington, D. C.

Adam Capen Gill, A. B., Ph. D., Ithaca, N. Y.; Assistant Professor of Mineralogy and Petrography in Cornell University. December, 1888.

Charles H. Gordon, M. S., Ph. D., Lincoln, Neb.; Superintendent of Schools. August, 1893.

Amadeus William Grabau, S. B., Cambridge, Mass.; Fellow in Paleontology, Harvard University. December, 1898.

Ulysses Sherman Grant, Ph. D., Evanston, Ill.; Professor of Geology, Northwestern University. December, 1890.

William Stukeley Gresley, Erie, Pa.; Mining Engineer. December, 1893.

George P. Grimsley, M. A., Ph. D., Topeka, Kan.; Professor of Geology in Washburn College. August, 1895.

Leon S. Griswold, A. B., 238 Boston St., Dorchester, Mass. August, 1892.

Frederick P. Gulliver, A. M., St. Mark's School, Southboro, Mass. August, 1895.

Arnold Hague, Ph. B., U. S. Geological Survey, Washington, D. C. May, 1889.

* Christopher W. Hall, A. M., 803 University Ave., Minneapolis, Minn.; Professor of Geology and Mineralogy in University of Minnesota.

John B. Hastings, M. E., Rossland, British Columbia. May, 1889.

John B. Hatcher, Ph. B., Princeton, N. J.; Assistant in Geology, College of New Jersey. August, 1895.

* Erasmus Haworth, Ph. D., Lawrence, Kan.; Professor of Geology, University of Kansas.

C. Willard Hayes, Ph. D., U. S. Geological Survey, Washington, D. C. May, 1889.

* Angelo Heilprin, Academy of Natural Sciences, Philadelphia, Pa.; Professor of Paleontology in the Academy of Natural Sciences.

* Eugene W. Hilgard, Ph. D., LL. D., Berkeley, Cal.; Professor of Agriculture in University of California.

Frank A. Hill, Roanoke, Va. May, 1889.

* Robert T. Hill, B. S., U. S. Geological Survey, Washington, D. C.

Richard C. Hills, Mining Engineer, Denver, Colo. August, 1894.

* Charles H. Hitchcock, Ph. D., LL. D., Hanover, N. H.; Professor of Geology in Dartmouth College.

William Herbert Hobbs, B. Sc., Ph. D., Madison, Wis.; Assistant Professor of Mineralogy in the University of Wisconsin. August, 1891.

* Levi Holbrook, A. M., P. O. Box 536, New York city.

Arthur Hollick, Ph. B., Columbia University, New York; Instructor in Geology. August, 1893.

* Joseph A. Holmes, Chapel Hill, N. C.; State Geologist and Professor of Geology in University of North Carolina.

Thomas C. Hopkins, A. M., Walker Museum, University of Chicago. Dec., 1894.

* Edmund Otis Hovey, Ph. D., American Museum of Natural History, New York city; Assistant Curator of Geology.

* Horace C. Hovey, D. D., Newburyport, Mass.

* Edwin E. Howell, A. M., 612 Seventeenth St. N. W., Washington, D. C.

Lucius L. Hubbard, A. B., LL. D., Ph. D., Houghton, Mich.; State Geologist of Michigan. December, 1894.

* Alpheus Hyatt, B. S., Boston Society of Natural History, Boston, Mass.; Curator of Boston Society of Natural History.

Joseph P. Iddings, Ph. B., Professor of Petrographic Geology, University of Chicago, Chicago, Ill. May, 1889.

A. Wendell Jackson, Ph. B., 407 St. Nicholas Ave., New York city. Dec., 1888.

Robert T. Jackson, S. B., S. D., 33 Gloucester St., Boston, Mass.; Instructor in Paleontology in Harvard University. August, 1894.

Thomas M. Jackson, C. E., S. D., Clarksburg, W. Va. May, 1889.

* Willard D. Johnson, United States Geological Survey, Washington, D. C.

Alexis A. Julien, Ph. D., Columbia College, New York city; Instructor in Columbia College. May, 1889.

Arthur Keith, A. M., U. S. Geological Survey, Washington, D. C. May, 1889.

* James F. Kemp, A. B., E. M., Columbia University, New York city; Professor of Geology.

Charles Rollin Keyes, A. M., Ph. D., 944 Fifth St., Des Moines, Iowa. Aug., 1890.

Wilbur C. Knight, B. S., A. M., Laramie, Wyo.; Professor of Mining and Geology in the University of Wyoming. August, 1897.

Frank H. Knowlton, M. S., Washington, D. C.; Assistant Paleontologist, U. S. Geological Survey. May, 1889.

Henry B. Kümmel, A. M., Ph. D., Trenton, N. J.; Assistant State Geologist. December, 1895.

*George F. Kunz, care of Tiffany & Co., 15 Union Square, New York city.

Ralph D. Lacoe, Pittston, Pa. December, 1889.

George Edgar Ladd, A. M., Ph., D., Rolla, Mo.; Director, School of Mines. August, 1891.

J. C. K. Laflamme, M. A., D. D., Quebec, Canada; Professor of Mineralogy and Geology in University Laval, Quebec. August, 1890.

Alfred C. Lane, Ph. D., Lansing, Mich.; Assistant State Geologist. Dec., 1889.

Daniel W. Langton, Ph. D., 39 East Tenth St., New York city; Mining Engineer. December, 1889.

Andrew C. Lawson, Ph. D., Berkeley, Cal.; Assistant Professor of Geology in the University of California. May, 1889.

*Joseph Le Conte, M. D., LL. D., Berkeley, Cal.; Professor of Geology in the University of California.

*J. Peter Lesley, LL. D., 1008 Clinton St., Philadelphia, Pa.; State Geologist.

Frank Leverett, B. S., Denmark, Iowa; Asst., U. S. Geol. Survey. Aug., 1890.

William Libbey, Sc. D., Princeton, N. J.; Professor of Physical Geography in Princeton University. August, 1899.

Waldemar Lindgren, U. S. Geological Survey, Washington, D. C. August, 1890.

Robert H. Loughridge, Ph. D., Berkeley, Cal.; Assistant Professor of Agricultural Chemistry in University of California. May, 1889.

Albert P. Low, B. S., Geological Survey Office, Ottawa, Canada; Geologist on Canadian Geological Survey. August, 1892.

Thomas H. Macbride, Iowa City, Iowa; Professor of Botany in the State University of Iowa. May, 1889.

Henry McCalley, A. M., C. E., University, Tuscaloosa county, Ala.; Assistant on Geological Survey of Alabama. May, 1889.

Richard G. McConnell, A. B., Geological Survey Office, Ottawa, Canada; Geologist on Geological and Natural History Survey of Canada. May, 1889.

James Rieman Macfarlane, A. B., 100 Diamond St., Pittsburg, Pa. August, 1891.

*W J McGee, Washington, D. C.; Bureau of North American Ethnology.

William McInnes, A. B., Geological Survey Office, Ottawa, Canada; Geologist, Geological and Natural History Survey of Canada. May, 1889.

Peter McKellar, Fort William, Ontario, Canada. August, 1890.

Cyrus F. Marbut, A. M., State University, Columbia, Mo.; Instructor in Geology and Assistant on Missouri Geological Survey. August, 1897.

Vernon F. Masters, A. M., Bloomington, Ind.; Professor of Geology in Indiana State University. August, 1892.

Edward B. Mathews, Ph. D., Baltimore, Md.; Instructor in Petrography in Johns Hopkins University. August, 1895.

P. H. Mell, M. E., Ph. D., Auburn, Ala.; Professor of Geology and Natural History in the State Polytechnic Institute. December, 1888.

John C. Merriam, Ph. D., Berkeley, Cal.; Instructor in Paleontology in University of California. August, 1895.

*Frederick J. H. Merrill, Ph. D., State Museum, Albany, N. Y.; Assistant State Geologist and Assistant Director of State Museum.

George P. Merrill, M. S., U. S. National Museum, Washington, D. C.; Curator of Department of Lithology and Physical Geology. December, 1888.

Arthur M. Miller, A. M., Lexington, Ky.; Professor of Geology, State University of Kentucky. December, 1897.

James E. Mills, B. S., Quincy, Plumas Co., Cal. December, 1888.

Thomas F. Moses, M. D., Worcester Lane, Waltham, Mass. May, 1889.

* Frank L. Nason, A. B., West Haven, Conn.

* Peter Neff, A. M., 361 Russell Ave., Cleveland, Ohio; Librarian, Western Reserve Historical Society.

Frederick H. Newell, B. S., U. S. Geol. Survey, Washington, D. C. May, 1889.

William H. Niles, Ph. B., M. A., Cambridge, Mass. August, 1891.

William H. Norton, M. A., Mt. Vernon, Iowa; Professor of Geology in Cornell College. December, 1895.

Charles J. Norwood, Frankfort, Ky.; Mining Engineer. August, 1894.

Ezequiel Ordonez, Esquela N. de Ingeneiros, City of Mexico, Mexico; Geologist del Instituto Geologico de Mexico. August, 1896.

* Amos O. Osborn, Waterville, Oneida Co., N. Y.

Henry F. Osborn, Sc. D., Columbia University, New York city; Professor of Zoology, Columbia University. August, 1897.

Charles Palache, B. S., University Museum, Cambridge, Mass.; Instructor in Mineralogy, Harvard University. August, 1894.

* Horace B. Patton, Ph. D., Golden, Colo.; Professor of Geology and Mineralogy in Colorado School of Mines.

Richard A. F. Penrose, Jr., Ph. D., 1331 Spruce St., Philadelphia, Pa. May, 1889.

Joseph H. Perry, 176 Highland St., Worcester, Mass. December, 1888.

* William H. Pettee, A. M., Ann Arbor, Mich.; Professor of Mineralogy, Economical Geology, and Mining Engineering in Michigan University.

Louis V. Pirsson, Ph. D., New Haven, Conn.; Assistant Professor of Inorganic Geology, Sheffield Scientific School. August, 1894.

* Franklin Platt, 1617 Chestnut St., Philadelphia, Pa.

* Julius Pohlman, M. D., University of Buffalo, Buffalo, N. Y.

John Bonsall Porter, E. M., Ph. D., Montreal, Canada; Professor of Mining, McGill University. December, 1896.

* John W. Powell, Bureau of Ethnology, Washington, D. C.

Joseph Hyde Pratt, Ph. D., Chapel Hill, N. C.; Assistant Geologist, North Carolina Geological Survey. December, 1898.

* Charles S. Prosser, M. S., Columbus, Ohio; Associate Professor of Historical Geology in Ohio State University.

* Raphael Pumpelly, U. S. Geological Survey, Dublin, N. H.

Edmund C. Quereau, Ph. D., Aurora, Ill.; Professor of Geology, Syracuse University. August, 1897.

Frederick Leslie Ransome, Ph. D., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1895.

Harry Fielding Reid, Ph. D., Johns Hopkins Univ., Baltimore, Md. Dec., 1892.

William North Rice, A. M., Ph. D., LL. D., Middletown, Conn.; Professor of Geology in Wesleyan University. August, 1890.

Heinrich Ries, A. M., Ph. D., Cornell University, Ithaca, N. Y.; Instructor in Economic Geology. December, 1893.

Charles W. Rolfe, M. S., 601 John St., Champaign, Ill.; Professor of Geology in University of Illinois. May, 1889.

* Israel C. Russell, LL. D., Ann Arbor, Mich.; Professor of Geology in University of Michigan.

*James M. Safford, M. D., LL. D., Nashville, Tenn.; State Geologist; Professor in Vanderbilt University.

Orestes H. St. John, Raton, N. Mex. May, 1889.

*Rollin D. Salisbury, A. M., Chicago, Ill.; Professor of General and Geographic Geology in University of Chicago.

Frederick W. Sardeson, L. B., M. S., Ph. D., Instructor in Paleontology, University of Minnesota, Minneapolis, Minn. December, 1892.

*Charles Schaeffer, M. D., 1309 Arch St., Philadelphia, Pa.

Charles Schuchert, Washington, D. C.; Assistant Curator in Paleontology, U. S. National Museum. August, 1895.

William B. Scott, M. A., Ph. D., 56 Bayard Ave., Princeton, N. J.; Blair Professor of Geology in College of New Jersey. August, 1892.

Henry M. Seely, M. D., Middlebury, Vt.; Professor of Geology in Middlebury College. May, 1889.

*Nathaniel S. Shaler, LL. D., Cambridge, Mass.; Professor of Geology in Harvard University.

George Burbank Shattuck, Ph. D., Baltimore, Md.; Associate Professor in Physiographic Geology, Johns Hopkins University. August, 1899.

Will H. Sherzer, M. S., Ypsilanti, Mich.; Professor in State Normal School. December, 1890.

*Frederick W. Simonds, Ph. D., Austin, Texas; Professor of Geology in University of Texas.

*Eugene A. Smith, Ph. D., University, Tuscaloosa Co., Ala.; State Geologist and Professor of Chemistry and Geology in University of Alabama.

Frank Clemes Smith, B. S., Deadwood, S. Dak.; Mining Engineer. Dec., 1898.

George Otis Smith, Ph. D., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1897.

*John C. Smock, Ph. D., Trenton, N. J.; State Geologist.

Charles H. Smyth, Jr., Ph. D., Clinton, N. Y.; Professor of Geology in Hamilton College. August, 1892.

Henry L. Smyth, A. B., Cambridge, Mass.; Instructor in Mining Geology in Harvard University. August, 1894.

Arthur Coe Spencer, B. S., Ph. D., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1896.

*J. W. Spencer, A. M., Ph. D., 152 Bloor St. East, Toronto, Canada.

Josiah E. Spurr, A. B., A. M., U. S. Geol. Survey, Washington, D. C. Dec., 1894.

Joseph Stanley-Brown, 1318 Massachusetts Ave., Washington, D. C. August, 1892.

Timothy William Stanton, B. S., U. S. National Museum, Washington, D. C.; Assistant Paleontologist, U. S. Geological Survey. August, 1891.

*John J. Stevenson, Ph. D., LL. D., New York University; Professor of Geology in the New York University.

Joseph A. Taff, B. S., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1895.

James E. Talmage, Ph. D., Salt Lake City, Utah; Professor of Geology in University of Utah. December, 1897.

Ralph S. Tarr, Cornell University, Ithaca, N. Y.; Professor of Dynamic Geology and Physical Geography. August, 1890.

Frank B. Taylor, Fort Wayne, Ind. December, 1895.

William G. Tight, M. S., Granville, Ohio; Professor of Geology and Biology, Denison University. August, 1897.

*James E. Todd, A. M., Vermilion, S. Dak.; Professor of Geology and Mineralogy in University of South Dakota.

*Henry W. Turner, B. S., U. S. Geological Survey, Washington, D. C.

Joseph B. Tyrrell, M. A., B. Sc., Geological Survey Office, Ottawa, Canada; Geologist on the Canadian Geological Survey. May, 1889.

Johan A. Udden, A. M., Rock Island, Ill.; Professor of Geology and Natural History in Augustana College. August, 1897.

*Warren Upham, A. M., Librarian Minnesota Historical Society, St. Paul, Minn.

*Charles R. Van Hise, M. S., Madison, Wis.; Professor of Mineralogy and Petrography in Wisconsin University; Geologist, U. S. Geological Survey.

Frank Robertson Van Horn, Ph. D., Cleveland, Ohio; Instructor in Geology and Mineralogy, Case School of Applied Science. December, 1898.

Thomas Wayland Vaughan, B. S., A. B., A. M., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1896.

*Anthony W. Vogdes, Fort Wadsworth, Staten Island, N. Y.; Captain Fifth Artillery, U. S. Army.

*Marshman E. Wadsworth, Ph. D., Box 296, Chicago, Ill.

*Charles D. Walcott, U. S. National Museum, Washington, D. C.; Director U. S. Geological Survey.

Henry Stephens Washington, B. A., M. A., Ph. D., Locust, Monmouth Co., N. J. August, 1896.

Walter H. Weed, M. E., U. S. Geological Survey, Washington, D. C. May, 1889.

Lewis G. Westgate, Ph. D., 805 Sherman Ave., Evanston, Ill. August, 1894.

Thomas C. Weston, Ottawa, Canada. August, 1893.

David White, U. S. National Museum, Washington, D. C.; Assistant Paleontologist, U. S. Geological Survey, Washington, D. C. May, 1889.

*Israel C. White, Ph. D., Morgantown, W. Va.

Theodore Greely White, Ph. B., A. M., New York city; Assistant in Physics, Columbia University. December, 1898.

*Robert P. Whitfield, Ph. D., American Museum of Natural History, 78th St. and Eighth Ave., New York city; Curator of Geology and Paleontology.

*Edward H. Williams, Jr., A. C., E. M., 117 Church St., Bethlehem, Pa.; Professor of Mining Engineering and Geology in Lehigh University.

*Henry S. Williams, Ph. D., New Haven, Conn.; Professor of Geology and Paleontology in Yale University.

Bailey Willis, U. S. Geological Survey, Washington, D. C. December, 1889.

Samuel Wendell Williston, Ph. D., M. D., Lawrence, Kan.; Professor of Historical Geology, University of Kansas. December, 1898.

*Horace Vaughn Winchell, Butte, Montana; Geologist of the Anaconda Copper Mining Company.

*Newton H. Winchell, A. M., Minneapolis, Minn.; State Geologist; Professor in University of Minnesota.

*Arthur Winslow, B. S., care of Missouri, Kansas and Texas Trust Company, Kansas City, Mo.

John E. Wolff, Ph. D., Harvard University, Cambridge, Mass.; Professor of Petrography and Mineralogy in Harvard University and Curator of the Mineralogical Museum. December, 1889.

Robert Simpson Woodward, C. E., Columbia College, New York city; Professor of Mechanics in Columbia College. May, 1889.

Jay B. Woodworth, B. S., 27 Dana St., Cambridge, Mass; Instructor in Harvard University. December, 1895.

Albert A. Wright, A. M., Ph. D., Oberlin, Ohio; Professor of Geology in Oberlin College. August, 1893.

*G. Frederick Wright, D. D., Oberlin, Ohio; Professor in Oberlin Theological Seminary.

William S. Yeates, A. B., A. M., Atlanta, Ga.; State Geologist of Ga. Aug., 1894.

FELLOWS DECEASED

*Indicates Original Fellow (see article III of Constitution)

*Charles A. Ashburner, M. S., C. E. Died December 24, 1889.
Amos Bowman. Died June 18, 1894.
*J. H. Chapin, Ph. D. Died March 14, 1892.
George H. Cook, Ph. D., LL. D. Died September 22, 1889.
*Edward D. Cope, Ph. D. Died April 12, 1897.
Antonio del Castillo. Died October 28, 1895.
*James D. Dana, LL. D. Died April 14, 1895.
Sir J. William Dawson, LL. D. Died November 19, 1899.
*Albert E. Foote. Died October 10, 1895.
N. J. Giroux, C. E. Died November 30, 1896.
*James Hall, LL. D. Died August 7, 1898.
*Robert Hay. Died December 14, 1895.
David Honeyman, D. C. L. Died October 17, 1889.
Thomas Sterry Hunt, D. Sc., LL. D. Died February 12, 1892.
*Joseph F. James, M. S. Died March 29, 1897.
Oliver Marcy, LL. D. Died March 19, 1899.
Othniel C. Marsh, Ph. D., LL. D. Died March 18, 1899.
*Henry B. Nason, M. D., Ph. D., LL. D. Died January 17, 1895.
*John S. Newberry, M. D., LL. D. Died December 7, 1892.
*Edward Orton, Ph. D., LL. D. Died October 16, 1899.
*Richard Owen, LL. D. Died March 24, 1890.
Charles Wachsmuth. Died February 7, 1896.
*George H. Williams, Ph. D. Died July 12, 1894.
*J. Francis Williams, Ph. D. Died November 9, 1891.
*Alexander Winchell, LL. D. Died February 19, 1891.

Summary.

Original Fellows	78
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ACCESSIONS TO LIBRARY FROM MARCH, 1898, TO MARCH, 1899

By H. P. Cushing, *Librarian*

Contents

(*A*) From Societies and Institutions receiving the Bulletin as Donation ("Exchanges")

(*a*) *AMERICA*

NEW YORK STATE MUSEUM, ALBANY

1500. Annual Report, no. 50, part 1, 1896.

BOSTON SOCIETY OF NATURAL HISTORY, BOSTON

1267. Proceedings, vol. xxviii, parts 7-14.

MUSEO NACIONAL DE BUENOS AIRES, BUENOS AIRES

1539. Comunicaciones, tomo i, núm. i, 1898.

CHICAGO ACADEMY OF SCIENCES, CHICAGO

FIELD COLUMBIAN MUSEUM, CHICAGO

1030. Publications 26, 27, Zoological Series, vol. i, nos. 9, 10, 1898.
1031. " 29, Report Series, vol. i, no. 4, 1898.

CINCINNATI SOCIETY OF NATURAL HISTORY, CINCINNATI

1034. Journal, vol. xix, no. 4, 1898.

COLORADO SCIENTIFIC SOCIETY, DENVER

1482. Proceedings, vol. v, 1894-'96.

NOVA SCOTIAN INSTITUTE OF SCIENCE, HALIFAX

MUSEO DE LA PLATA, LA PLATA

1477. Revista, tomo ix, pp. 1–79, 1898.
1484. Annales, Anthropologie, ii; Notes Ethnographiques sur les Indiens Guyaquis, etcetera, 1898.
1485. Reconnaissance de la Region Andine, 1.
1512. Revista, tomo viii, 1898, royal 8vo.

INSTITUTO GEOLOGICO DE MEXICO, MEXICO

1563. Boletin, núm. 10, Bibliografia, etcetera, 1898.

NATURAL HISTORY SOCIETY, MONTREAL

AMERICAN GEOGRAPHICAL SOCIETY, NEW YORK

1445. Bulletin, vol. xxx, nos. 1–5, 1898.

AMERICAN MUSEUM OF NATURAL HISTORY, NEW YORK

1486. Annual Report of the President, etcetera, 1897, pp. 1–123.
1507. Bulletin, vol. xi, part i, 1898.
1564. " " x, 1898, pp. 1–478, pls. 1–24.

NEW YORK ACADEMY OF SCIENCES, NEW YORK

1491. Annals, vol. xi, parts 1, 2, 1898.
1498. Transactions, vol. xvi, 1896–'97.
1578. Annals, vol. x, 1898.

GEOLOGICAL SURVEY OF CANADA, OTTAWA

1447–1449. Annual Reports (new series), vols. vi–viii, 1893–'95, with maps.
1523. Annual Report (new series), vol. ix, 1896.

ROYAL SOCIETY OF CANADA, OTTAWA

1524–1526. Proceedings, second series, vols. i–iii, 1895–'97.

ACADEMY OF NATURAL SCIENCES, PHILADELPHIA

1279. Proceedings, vol. 1897, part iii.
1461. " " 1898, parts i–iii.

AMERICAN PHILOSOPHICAL SOCIETY, PHILADELPHIA

1280. Proceedings, vol. xxxvi, no. 156.
1495. " " xxxvii, no. 157.

MUSEO NACIONAL DO RIO DE JANEIRO, RIO DE JANEIRO

CALIFORNIA ACADEMY OF SCIENCES, SAN FRANCISCO

1282. Proceedings, third series, Geology, vol. i, no. 4, 1898.

GEOLOGICAL SURVEY OF NEWFOUNDLAND, ST JOHNS

ACADEMY OF SCIENCE, ST LOUIS

1053. Transactions, vol. vii, nos. 18–20.
1454. “ “ viii, nos. 1–6.

COMMISSAO GEOGRAPHICA E GEOLOGICO, SAO PAULO

NATIONAL GEOGRAPHIC SOCIETY, WASHINGTON

1057. National Geographic Magazine, vol. viii, no. 12, 1897.
1457. “ “ “ “ ix, nos. 1–12, 1898.

LIBRARY OF CONGRESS, WASHINGTON

SMITHSONIAN INSTITUTION, WASHINGTON

UNITED STATES GEOLOGICAL SURVEY, WASHINGTON

1462–1463. Eighteenth Annual Report, part v, 2 vols., 1896–'97.
1528–1534. Bulletins, nos. 150–156, 1898.
1574–1576. “ “ 88, 89, and 149, 1898.
1577. Monograph no. xxx, 1898.

UNITED STATES NATIONAL MUSEUM, WASHINGTON

1649. Descriptions of the species of Cycadeoidea, etcetera.

(*b*) *EUROPE*

DEUTSCHE GEOLOGISCHE GESELLSCHAFT, BERLIN

1326. Zeitschrift, band xlix, heft iii–iv, 1897.
1509. “ “ l, heft i–ii, 1898.

KÖNIGLICH PREUSSISCHEN GEOLOGISCHEN LANDESANSTALT UND BERGAKADEMIE, BERLIN

GEOGRAPHISCHEN GESELLSCHAFT, BERNE

R. ACCADEMIA DELLE SCIENZE DELL' INSTITUTO DI BOLOGNA, BOLOGNA

1502. Memorie, serie v, tomo vi, 1897, 4to.

ACADÉMIE ROYALE DES SCIENCES, BRUSSELS

SOCIÉTÉ BELGE DE GÉOLOGIE, DE PALÉONTOLOGIE ET D'HYDROLOGIE, BRUSSELS

1331. Bulletin, tome x, fasc. 2–3, 1896.
1444. “ “ xi, fasc. 1–3, 1897.

BIUROULI GEOLOGICA, BUCHAREST

1435. Harta Geologica generala a Romaniei, sheets xliv–xlvii.
1584. Anuarulŭ, Mus. de geol. si de Paleon., 1895, 227 pp., 5 pl.

MAGYARHONI FÖLDTANI TARSULAT, BUDAPEST

1333. Földtani Közlöny, xxvii Kötet, 11–12 Fuset, 1897.
1503. " " xxviii Kötet, 1–9 Fuset, 1898.

NORGES GEOLOGISKE UNDERSOGELSE, CHRISTIANA

ACADÉMIE ROYALE DES SCIENCES ET DES LETTRES DE DANEMARK, COPENHAGEN

1334. Oversigt i Aaret, 1897, nr. 6.
1483. " " " 1898, nr. 1–5.

NATURWISSENSCHAFTLICHEN GESELLSCHAFT ISIS, DRESDEN

1335. Sitzungsberichte und Abhandlungen, Jahrg. 1897, Jul.–Dec.
1527. " " " " 1898, Jan.–Jun.

ROYAL SOCIETY OF EDINBURGH, EDINBURGH

1124. Transactions, vol. xxxviii, parts 3–4, 1894–'95, 4to.
1489. " " xxxix, part 1, 1896–'97, 4to.
1400. Proceedings, vol. xxi, 1895–'97, 8vo.

NATURFORSCHENDEN GESELLSCHAFT, FREIBURG, I. B.

1504. Berichte, band x, heft 1–3, 1898.

GEOLOGICAL SOCIETY OF GLASGOW, GLASGOW

PETERMANN'S GEOGRAPHISCHE MITTHEILUNGEN, GOTHA

KSL. LEOP. CAROL. DEUTSCHEN AKADEMIE DER NATURFORSCHER, HALLE

1451. Nova Acta, band lxviii, 1897, 680 pp., 25 pl.
1452. " " " lxix, 1898, 419 pp., 29 pl.
1453. Leopoldina, heft xxxiii, 1897.

GEOLOGISKA UNDERSOKNING, HELSINGFORS

1126. Beskrifning till kartbladet, nos. 32–33, 1896–'98, 2 maps.
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