FOR THE INCREASE AND DIFFVSION OF KNOWLEDGE AMONG MEN.

PER ORBEM

SMITHSONIAN INSTITVTION WASHINGTON 1846

ANNUAL REPORT OF THE
BOARD OF REGENTS OF

THE SMITHSONIAN INSTITUTION

SHOWING THE

OPERATIONS, EXPENDITURES, AND
CONDITION OF THE INSTITUTION
FOR THE YEAR ENDED JUNE 30

1936

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2. Report of the executive committee of the Board of Regents, exhibiting the financial affairs of the Institution, including a statement of the Smithsonian fund, and receipts and expenditures for the year ended June 30, 1936.

3. General appendix comprising a selection of miscellaneous memoirs of interest to collaborators and correspondents of the Institution, teachers, and others engaged in the promotion of knowledge. These memoirs relate chiefly to the calendar year 1936.

UNITED STATES NATIONAL MUSEUM

Keeper ex officio.—CHARLES G. ABBOT.
Assistant Secretary (in charge).—ALEXANDER WETMORE.
Associate director.—JOHN E. GRAF.

SCIENTIFIC STAFF

DEPARTMENT OF ANTHROPOLOGY:

Frank M. Setzler, acting head curator; W. H. Egberts, chief preparator.

Division of Ethnology: H. W. Krieger, curator; H. B. Collins, Jr., assistant curator; Arthur P. Rice, collaborator.

Section of Musical Instruments: Hugo Worch, custodian.

Section of Ceramics: Samuel W. Woodhouse, collaborator.

Division of Archeology: Neil M. Judd, curator; R. G. Paine, aid; J. Townsend Russell, honorary assistant curator of Old World archeology.

Division of Physical Anthropology: Aleš Hrdlička, curator; Thomas D. Stewart, assistant curator.

Collaborator in anthropology: George Grant MacCurdy; D. I. Bushnell, Jr.
Associate in historic archeology: Cyrus Adler.

DEPARTMENT OF BIOLOGY:

Leonhard Stejneger, head curator; W. L. Brown, chief taxidermist.

Division of Mammals: Gerrit S. Miller, Jr., curator; Remington Kellogg, assistant curator; A. J. Poole, scientific aid; A. Brazier Howell, collaborator.

Division of Birds: Herbert Friedmann, curator; J. H. Riley, associate curator; Alexander Wetmore, custodian of alcoholic and skeleton collections; Casey A. Wood, collaborator: Arthur C. Bent, collaborator.

Division of Reptiles and Batrachians: Leonhard Stejneger, curator; Doris M. Cochran, assistant curator.

Division of Fishes: George S. Myers, assistant curator; E. D. Reid, aid.

Division of Insects: L. O. Howard, honorary curator; Edward A. Chapin, curator; William Schaus, honorary assistant curator; B. Preston Clark, collaborator.

Section of Hymenoptera: S. A. Rohwer, custodian; W. M. Mann, assistant custodian; Robert A. Cushman, assistant custodian.

Section of Myriapoda: O. F. Cook, custodian.

Section of Diptera: Charles T. Greene, assistant custodian.

Section of Coleoptera: L. L. Buchanan, specialist for Casey collection.

Section of Lepidoptera: J. T. Barnes, collaborator.

Section of Hemiptera: W. L. McAtee, acting custodian.

Section of Forest Tree Beetles: A. D. Hopkins, custodian.

Division of Marine Invertebrates: Waldo L. Schmitt, curator; C. R. Shoemaker, assistant curator; James O. Maloney, aid; Mrs. Harriet Richardson Searle, collaborator; Max M. Ellis, collaborator; William H. Longley, collaborator; Maynard M. Metcalf, collaborator; J. Percy Moore, collaborator; Joseph A. Cushman, collaborator in Foraminifera; Charles Branch Wilson, collaborator in Copepoda.

Division of Mollusks: Paul Bartsch, curator; Harald A. Rehder, assistant curator; Joseph P. E. Morrison, senior scientific aid; Mary Breen, collaborator.

Section of Helminthological Collections: Maurice C. Hall, custodian.

Division of Echinoderms: Austin H. Clark, curator.

DEPARTMENT OF BIOLOGY—Continued.

Division of Plants (National Herbarium): Frederick V. Coville, honorary curator; W. R. Maxon, associate curator; Ellsworth P. Killip, associate curator; Emery C. Leonard, assistant curator; Conrad V. Morton, aid; Egbert H. Walker, aid; John A. Stevenson, custodian of C. G. Lloyd mycological collection.

Section of Cryptogamic Collections: O. F. Cook, assistant curator.

Section of Higher Algae: W. T. Swingle, custodian.

Section of Lower Fungi: D. G. Fairchild, custodian.

Section of Diatoms: Paul S. Conger, custodian.

Associates in Zoology: C. Hart Merriam, Mary J. Rathbun, C. W. Stiles Theodore S. Palmer, William B. Marshall.

Associate Curator in Zoology: Hugh M. Smith.

Associate in Marine Sediments: T. Wayland Vaughan.

Collaborator in Zoology: Robert Sterling Clark.

Collaborators in Biology: A. K. Fisher, David C. Graham.

DEPARTMENT OF GEOLOGY:

R. S. Bassler, head curator; Jessie G. Beach, aid.

Division of Physical and Chemical Geology (systematic and applied): W. F. Foshag, curator; Edward P. Henderson, assistant curator.

Division of Mineralogy and Petrology: W. F. Foshag, curator; Frank L. Hess, custodian of rare metals and rare earths.

Division of Stratigraphic Paleontology: Charles E. Resser, curator; Gustav A. Cooper, assistant curator; Margaret W. Moodey, aid for Springer collection.

Section of Invertebrate Paleontology: T. W. Stanton, custodian of Mesozoic collection; Paul Bartsch, curator of Cenozoic collection.

Division of Vertebrate Paleontology: Charles W. Gilmore, curator; C. Lewis Gazin, assistant curator; Norman H. Boss, chief preparator.

Associate in Mineralogy: W. T. Schaller.

Associate in Paleontology: E. O. Ulrich.

Associate in Petrology: Whitman Cross.

DEPARTMENT OF ARTS AND INDUSTRIES:

Carl W. Mitman, head curator.

Division of Engineering: Frank A. Taylor, curator.

Section of Mechanical Technology: Frank A. Taylor, in charge; Fred C. Reed, scientific aid.

Section of Aeronautics: Paul E. Garber, assistant curator.

Section of Mineral Technology: Carl W. Mitman, in charge.

Division of Textiles: Frederick L. Lewton, curator; Mrs. E. W. Rosson, aid.

Section of Wood Technology: William N. Watkins, assistant curator.

Section of Organic Chemistry: Aida M. Doyle, aid.

Division of Medicine: Charles Whitebread, assistant curator.

Division of Graphic Arts: R. P. Tolman, curator; C. Allen Sherwin, scientific aid.

Section of Photography: A. J. Olmsted, assistant curator.

DIVISION OF HISTORY: T. T. Belote, curator; Charles Carey, assistant curator; Mrs. C. L. Manning, philatelist.

ADMINISTRATIVE STAFF

Chief of correspondence and documents.—H. S. BRYANT.

Assistant chief of correspondence and documents.—L. E. COMMERFORD.

Superintendent of buildings and labor.—R. H. TREMBLY.

Assistant superintendent of buildings and labor.—CHARLES C. SINCLAIR.
Editor.—PAUL H. OEHSER.
Engineer.—C. R. DENMARK.
Accountant and auditor.—N. W. DORSEY.
Photographer.—A. J. OLMSTED.
Property clerk.—LAWRENCE L. OLIVER.
Assistant librarian.—LEILA F. CLARK.

NATIONAL GALLERY OF ART

Acting director.—RUEL P. TOLMAN.

FREER GALLERY OF ART

Curator.—JOHN ELLERTON LODGE.
Associate curator.—CARL WHITING BISHOP.
Assistant curator.—GRACE DUNHAM GUEST.
Assistant.—ARCHIBALD G. WENLEY.
Superintendent.—JOHN BUNDY.

BUREAU OF AMERICAN ETHNOLOGY

Chief.—MATTHEW W. STIRLING.
Ethnologists.—JOHN P. HARRINGTON, JOHN N. B. HEWITT, TRUMAN MICHELSON, JOHN R. SWANTON, WILLIAM D. STRONG.
Archeologist.—FRANK H. H. ROBERTS, Jr.
Associate anthropologist.—JULIAN H. STEWARD.
Editor.—STANLEY SEARLES.
Librarian.—MIRIAM B. KETCHUM.
Illustrator.—EDWIN G. CASSEDY.

INTERNATIONAL EXCHANGES

Secretary (in charge).—CHARLES G. ABBOT.
Chief clerk.—COATES W. SHOEMAKER.

NATIONAL ZOOLOGICAL PARK

Director.—WILLIAM M. MANN.
Assistant director.—ERNEST P. WALKER.

ASTROPHYSICAL OBSERVATORY

Director.—CHARLES G. ABBOT.
Assistant director.—LOYAL B. ALDRICH.
Research assistant.—FREDERICK E. FOWLE, Jr.
Associate research assistant.—WILLIAM H. HOOVER.

DIVISION OF RADIATION AND ORGANISMS

Director.—CHARLES G. ABBOT.
Assistant director.—EARL S. JOHNSTON.
Associate research assistant.—EDWARD D. McALISTER.
Assistant in radiation research.—LELAND B. CLARK.
Research associate.—FLORENCE E. MEIER.

REPORT OF THE SECRETARY OF THE SMITHSONIAN INSTITUTION

C. G. ABBOT

FOR THE YEAR ENDED JUNE 30, 1936

To the Board of Regents of the Smithsonian Institution:

GENTLEMEN: I have the honor to submit herewith my report showing the activities and condition of the Smithsonian Institution and the Government bureaus under its administrative charge during the fiscal year ended June 30, 1936. The first 16 pages contain a summary account of the affairs of the Institution, and appendixes 1 to 10 give more detailed reports of the operations of the National Museum, the National Gallery of Art, the Freer Gallery of Art, the Bureau of American Ethnology, the International Exchanges, the National Zoological Park, the Astrophysical Observatory, the Division of Radiation and Organisms, the Smithsonian library, and of the publications issued under the direction of the Institution. On page 97 is the financial report of the executive committee of the Board of Regents.

OUTSTANDING EVENTS

Notable progress has been made by the Institution in its varied fields of endeavor. Continuation of the study of the relation of our weather to changes in the sun's radiation led to apparent proof that the short-interval changes of solar radiation are of major influence on the weather for the following 2 weeks. Funds to establish seven additional observing stations to test this promising method of weather forecasting were provided in a bill passed by the Senate, but unfortunately the item was lost in conference. The Division of Radiation and Organisms has determined specifically the efficiency of different wave lengths of radiation in promoting photosynthesis and phototropism, and has developed new types of research apparatus of unequaled adaptability and power. The Institution published the latest results of the high-altitude rocket experiments of Dr. R. H. Goddard, whose early work was supported for 12 years by the Smithsonian. In his most recent trial flights the liquid-propelled rocket attained a height of 7,500 feet, its automatic stabilizer keeping the flight vertical. With the P. W. A. grant reported last year, three new modern

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exhibition buildings are under construction at the National Zoological Park and are expected to be completed by January 1937.

Toward the end of the year a weekly radio program on the activities of the Smithsonian Institution was put on the air by the Office of Education, Department of the Interior, in cooperation with the National Broadcasting Company. The program consists of weekly half-hour dramatizations of science and art over a Nation-wide hook-up. The mail response from listeners has been enthusiastic. The sales of the Smithsonian Scientific Series, a set of 12 popular science volumes written by members of the Smithsonian staff and collaborators, have continued to increase until at the present time a total of nearly $150,000 has been received by the Institution in royalties for the furtherance of its researches. In the will of the late Dr. William L. Abbott, long a collaborator and friend of the Institution, a one-fifth share of his residuary estate was left to the Smithsonian to promote zoological researches. The executors state that this share will be in the neighborhood of $100,000.

The Institution has continued its work on the problem of Folsom man through the investigations of Dr. F. H. H. Roberts, Jr., near Fort Collins, Colo. Additional information has been obtained on this earliest known American aboriginal culture, as well as further evidence of the contemporaneity of Folsom man with extinct species of bison. In Alaska Dr. Aleš Hrdlička and Henry B. Collins, working independently, have continued to seek for direct evidence of the ancient migration of the American Indians from Asia, with valuable results.

Outstanding among the year's publications were: Solar Radiation and Weather Studies and The Dependence of Terrestrial Temperatures on the Variations of the Sun's Radiation, by C. G. Abbot, summarizing his investigations on the relationship of our weather to variation in the sun's radiation; An Introduction to Nebraska Archeology, by William Duncan Strong, a monographic work on the archeology of that important region; and Molluscan Intermediate Hosts of the Asiatic Blood Fluke, *Schistosoma japonicum*, and Species Confused with Them, by Paul Bartsch, a definitive classification of the intermediate hosts of this human parasite, which affects millions of Orientals, particularly the Chinese. Suggestions for its control are included.

SUMMARY OF THE YEAR'S ACTIVITIES OF THE BRANCHES OF THE INSTITUTION

National Museum.—For the maintenance of the National Museum the total appropriations were $760,742, an increase of $44,671 over those for 1935. Additions to the collections numbered 486,581 speci-

mens, coming mostly as gifts or as the result of Smithsonian expeditions. Perhaps the most outstanding single accessions in the various departments of the Museum were as follows: In anthropology, the Richard K. Peck collection of materials representing the Negritos and Papuans of Dutch New Guinea, the Dyaks of Borneo, and the Jivaro of Ecuador; in biology, an accession of 465 mammals from Africa, Asia, and South America, representing 300 forms not previously contained in the collections, by exchange from the Field Museum of Natural History; in geology, a notable series of Chilean minerals, including six new species, collected by Mark Bandy; in arts and industries, the airplane *Winnie Mae*, flown by Post and Gatty and later by Post alone in various record flights, purchased through special Congressional appropriation. A number of field expeditions went out during the year, financed mainly by Smithsonian private funds. Visitors to the various Museum buildings numbered 1,973,673. There were published 1 annual report, 11 Proceedings papers, and 1 paper in the series Contributions from the National Herbarium.

National Gallery of Art.—A large part of the year's work related to the care, protection, and restoration of paintings belonging to the Government. In the interests of the better preservation of works of art and of better working conditions, an air-conditioning unit was installed in the storage workroom. At the 15th annual meeting of the National Gallery of Art Commission on December 10, 1935, the death of Joseph H. Gest, chairman, was announced, and Charles L. Borie, Jr., was elected chairman. A number of portraits and other art works were accepted by the Commission for the Gallery. Four miniatures were acquired through the Catherine Walden Myer fund. The Gallery held eight special exhibitions, as follows: National and international high school art; intaglio prints and etchings by members of the Chicago Society of Etchers; miniatures by members of the American Society of Miniature Painters; paintings and etchings by Mons Breidvik; portraits by Bjorn P. Egeli; vitreous enamels by Frances and Richard McGraw; the First Annual Metropolitan State Art Contest; and paintings by children receiving free art instruction in the New York area.

Freer Gallery of Art.—The year's additions to the collection include a Persian brass box, four Chinese bronzes, and a sculptured Persian pediment, all shown in plates 1 and 2. There were also added four leaves from a sixteenth century Persian manuscript, two Indian and three Persian paintings, and in pottery one Chinese cup and a Syro-Egyptian bowl. Curatorial work was devoted to the study of Chinese, Japanese, Armenian, Arabic, Persian, and East Indian objects and of the texts and seals associated with them. During the year 673 objects and 225 photographs of objects were submitted to the curator for an

opinion as to their identity, meaning, or historical or esthetic significance, and 18 inscriptions for translation. Visitors totaled 123,418, and 96 groups were given docent service. A course of four lectures on Persian Painting was given at the Gallery by Eustache de Lorey, former Director of the French Institute of Arts and Archaeology, and 19 lectures and illustrated talks were given by members of the Gallery staff at Columbia University and at the Gallery.

Bureau of American Ethnology.—The researches of the Bureau on the American Indians included archeological and ethnological studies in Washington, in many other parts of the United States, in Canada, and in Central America. In the field of archeology, aid was given in establishing two P. W. A. projects at two important old sites in Florida; further investigation of the problem of Folsom man was carried out through excavations at the Lindenmeier site in northern Colorado; a joint Smithsonian-Peabody Museum expedition made important archeological discoveries in Honduras, notably that of a culture level apparently ancestral to that of the Maya. The year's ethnological investigations included linguistic studies of the Timucua and of the Indians of James and Hudson Bays, Canada; study of the Mission Indians of California; field work among the Shoshoni, Bannock, and Gosiute Indians of Utah, Nevada, and Idaho; studies of the League of the Iroquois; and researches on Florida Indian music. The Bureau published an annual report and two bulletins.

International exchanges.—The exchange service is the official United States agency for the exchange with other countries of governmental and scientific documents. In carrying out this important work of aiding in the interchange of scientific thought among the nations of the world, the exchange service handled during the year a total of 596,951 packages weighing 618,789 pounds. The number of full and partial sets of governmental publications forwarded abroad is now 111, and 102 copies of the Congressional Record are sent to other countries in exchange for their parliamentary journals. The Exchange Agency in Peru, formerly conducted under the Ministerio de Fomento, Lima, is now under the jurisdiction of the Ministerio de Relaciones Exteriores, the Sección de Propaganda y Publicaciones in Lima carrying on the work. The agency for the Union of South Africa has been removed from Pretoria, Transvaal, to Capetown, Cape of Good Hope.

National Zoological Park.—Under a grant from the P. W. A. of $680,000, supplemented later by $191,575, work was begun during the year on five projects, namely, machine and carpenter shops and a garage; installation of three 250-h.p. boilers which will heat all exhibition buildings except the bird house; a building for small mammals and great apes; a building for large animals such as elephant, rhinoceros, and hippopotamus; and a new wing on the bird house.

With the completion of these projects, the Zoo will have four large modern exhibition buildings, and the new construction constitutes the greatest improvement in the history of the Park. Assignment of P. W. A. labor also enabled the Park to carry out a considerable number of lesser improvements, including work on roads, grounds, and buildings. Accessions of animals numbered 786. Losses by death and otherwise totalled 765, leaving the collection at the close of the year at 2,191 animals, representing 675 different species. Visitors numbered 2,235,850, including groups from 579 schools and organizations from 20 States and the District of Columbia.

Astrophysical Observatory.—Measurements of the solar constant of radiation have been continued on every possible day at the three Smithsonian stations at Table Mountain, Calif., Montezuma, Chile, and Mount St. Katherine, Egypt. The irregularity of the results at Table Mountain led to the development of a criterion for distinguishing unfavorable sky conditions, which will provide a new increase in the accuracy of measurement of the solar variability. Two papers published by Dr. Abbot appear to prove that the short-interval changes of solar radiation are of major influence on the weather for the ensuing 2 weeks or more. To test the use of this relationship in weather forecasting, seven additional observing stations are required. An amendment to the Urgent Deficiency Act providing the necessary funds was passed by the Senate, but was rejected in conference with the House. Preliminary studies were begun of the possibility of automatic determination of solar variability from sounding balloons.

Division of Radiation and Organisms.—The Division's investigations comprised the following: Continuation of work on the dependence of carbon dioxide assimilation in wheat upon the wave length of radiation; experiments on the effects of ultraviolet rays on algae; experiments on the effects of light of different wave lengths on growth of tomatoes; development of an extremely sensitive and quick-acting spectroscopic method for measuring carbon dioxide concentration; study of the dependence of photosynthesis in wheat on time factors; and the development of a highly sensitive thermocouple of great ruggedness.

THE ESTABLISHMENT

The Smithsonian Institution was created by act of Congress in 1846, according to the terms of the will of James Smithson, of England, who in 1826 bequeathed his property to the United States of America "to found at Washington, under the name of the Smithsonian Institution, an establishment for the increase and diffusion of knowledge among men." In receiving the property and accepting the trust, Congress determined that the Federal Government was without authority to administer the trust directly, and, therefore,

constituted an "establishment" whose statutory members are "the President, the Vice President, the Chief Justice, and the heads of the executive departments."

The terms of the three Members of the House of Representatives on the Board of Regents, Representatives T. Alan Goldsborough, of Maryland; Charles L. Gifford, of Massachusetts; and Clarence Cannon, of Missouri, expired on December 25, 1935, and on January 9, 1936, they were reappointed by the Speaker of the House for the statutory term of 2 years. Mr. Frederic A. Delano, of Washington, D. C., whose term as a citizen Regent expired January 21, 1935, was reappointed for another 6 years by Joint Resolution of Congress approved August 7, 1935. By Joint Resolution of Congress approved February 21, 1936, Dr. Roland S. Morris, of Philadelphia, Pennsylvania, was appointed to fill the existing vacancy in the class of citizen Regents.

The roll of Regents at the close of the year was as follows: Charles Evans Hughes, Chief Justice of the United States, Chancellor; John N. Garner, Vice President of the United States; members from the Senate—Joseph T. Robinson, M. M. Logan, Charles L. McNary; members from the House of Representatives—T. Alan Goldsborough, Clarence Cannon, Charles L. Gifford; citizen members—Frederic A. Delano, Washington, D. C.; John C. Merriam, Washington, D. C.; R. Walton Moore, Virginia; Robert W. Bingham, Kentucky; Augustus P. Loring, Massachusetts; Roland S. Morris, Pennsylvania.

Proceedings.—The annual meeting of the Board of Regents was held on January 16, 1936. The Regents present were Chief Justice Charles Evans Hughes, Chancellor; Senators Joseph T. Robinson and M. M. Logan; Representatives Charles L. Gifford and Clarence Cannon; citizen Regents Frederic A. Delano, Augustus P. Loring; and the Secretary, Dr. Charles G. Abbot.

The Board elected Senator McNary a member of the Permanent Committee.

The Secretary presented his annual report, detailing the activities of the several Government branches and of the parent Institution during the year, and Mr. Delano presented the report of the Executive Committee, covering financial statistics of the Institution. The Secretary also presented the annual report of the National Gallery of Art Commission.

In his usual special report the Secretary briefly reviewed outstanding events of the year, and Assistant Secretary Wetmore detailed important activities in the National Museum.

FINANCES

A statement will be found in the report of the executive committee, page 97.

MATTERS OF GENERAL INTEREST

SMITHSONIAN RADIO PROGRAM

A new means of carrying on the diffusion of knowledge was made available to the Institution toward the end of the fiscal year, when the Office of Education, Department of the Interior, began, as a feature of the Radio Project of the Works Progress Administration, a series of weekly half-hour radio broadcasts, on a Nation-wide hook-up, on the activities of the Smithsonian Institution. These broadcasts, which constitute an innovation in the field of educational radio programs, take the form of dramatizations of the scientific research, exploration, museum exhibits, and art activities carried on under the Institution's direction. They form an N. B. C. blue network feature on Sunday mornings at 11:30 Eastern daylight saving time (red network, 11:30 Eastern standard time after September 27), and are presented through the cooperation of the National Broadcasting Co.

The first broadcast, produced on Sunday, June 7, 1936, dramatized the founding of the Smithsonian Institution and the stories of some of the famous exhibits in the Arts and Industries Building of the United States National Museum, including Colonel Lindbergh's *Spirit of St. Louis*, the Star Spangled Banner, the first Atlantic cable, and Alexander Graham Bell's early telephones. This, with the 13 other broadcasts listed below, were to comprise the first series:

The Smithsonian, and Famous Exhibits	June 7, 1936
Scientific Explorations	June 14, 1936
The Sun	June 21, 1936
The American Indian	June 28, 1936
Costumes of Ladies of the White House	July 5, 1936
Transportation	July 12, 1936
Meteorites	July 19, 1936
The Human Side of Art	July 26, 1936
Mammals	Aug. 2, 1936
Power	Aug. 9, 1936
The Story of Man in America	Aug. 16, 1936
Textiles	Aug. 23, 1936
Precious Stones	Aug. 30, 1936
Ship Models	Sept. 6, 1936

From the beginning this program has been enthusiastically received. Hundreds of letters were received at the Office of Education commending the dramatized form of educational broadcast as being both entertaining and instructive, and I may anticipate the next fiscal

year by saying that at the writing of this report in the early fall of 1936 the mail response had increased to an average of over 2,000 letters a week. A large number of the letters come from teachers and others particularly interested in education, many of whom state that the informative material contained in the dramatized stories of research, exploration and art, and in the advance summaries mailed out to those requesting them, is of real, practical use in their work.

The Institution is grateful to the Office of Education and to the National Broadcasting Co. for making possible this effective means of disseminating knowledge in the fields of science and art.

ROCKET EXPERIMENTS OF DR. R. H. GODDARD

For 12 years—from 1916 to 1928—the Institution supported through annual grants Dr. R. H. Goddard's investigations on rocket flight, with the primary purpose of supplying a means of exploring the unknown upper atmosphere. Dr. Goddard's pioneering researches on the design of the rocket itself and on the most effective rocket fuel and the means of utilizing it in the rocket led to a successful trial flight in July 1929, and in my annual report for 1930 I said:

The apparently assured success of Dr. Goddard's experiments has drawn support from a source better equipped financially to provide it than the Smithsonian. The late Simon Guggenheim, at Colonel Lindbergh's suggestion, made a large grant of funds and set up an advisory committee, of which the Secretary, Dr. Abbot, is a member. Dr. Goddard's experiments are now going on under these auspices in New Mexico. It is a pleasure to record here that the Smithsonian has again been able to support during its more or less uncertain pioneering stages an investigation of great promise for the increase of knowledge.

Dr. Goddard has continued to advance the development of his liquid-propellant rocket with marked success, and early in 1936 he made a report on these later researches to the Daniel and Florence Guggenheim Foundation. From this report, which was published by the Smithsonian Institution on March 16, 1936, it will be of interest to quote a few paragraphs:

Inasmuch as control by a small gyroscope is the best as well as the lightest means of operating the directing vanes, the action of the gyroscope being independent of the direction and acceleration of the rocket, a gyroscope having the necessary characteristics was developed after numerous tests.

The gyroscope was set to apply controlling force when the axis of the rocket deviated 10° or more from the vertical. In the first flight of the present series of tests with gyroscopic control, on March 28, 1935, the rocket as viewed from the 1,000-foot shelter traveled first to the left and then to the right, thereafter describing a smooth and rather flat trajectory. * * *

In subsequent flights, with adjustments and improvements in the stabilizing arrangements, the rockets have been stabilized up to the time propulsion ceased, the trajectory being a smooth curve beyond this point. * * * The oscillations each side of the vertical varied from 10° to 30° and occupied from 1 to 2

seconds. Inasmuch as the rockets started slowly, the first few hundred feet of the flight reminded one of a fish swimming in a vertical direction. * * *

The continually increasing speed of the rockets, with the accompanying steady roar, make the flights very impressive. In the two flights the rocket left a smoke trail and had a small, intensely white flame issuing from the nozzle, which at times nearly disappeared with no decrease in roar or propelling force. The occasional white flashes below the rocket are explosions of gasoline vapor in the air.

In the flight of October 14, 1935, the rocket rose 4,000 feet; in the flight of May 31, 1935, it rose 7,500 feet. * * *

As in the flights of 1930–32 to study rocket performance in the air, no attempt was made in the flights of 1934–35 to reduce the weight of the rockets, which varied from 58 to 85 pounds. A reduction of weight would be useless before a vertical course of the rocket could be maintained automatically. The speed of 700 miles per hour, although high, was not as much as could be obtained by a light rocket, and the heights also were much less than could be obtained by a light rocket of the same power.

It is worth mentioning that inasmuch as the delicate directional apparatus functioned while the rockets were in flight, it should be possible to carry recording instruments on the rocket without damage or changes in adjustment.

The next step in the development of the liquid-propellant rocket is the reduction of weight to a minimum. Some progress along this line has already been made. * * *

The chief accomplishments to date are the development of a combustion chamber, or rocket motor, that is extremely light and powerful and can be used repeatedly, and of a means of stabilization that operates automatically while the rocket is in flight.

WALTER RATHBONE BACON TRAVELING SCHOLARSHIP

DR. MOZLEY'S MOLLUSK INVESTIGATIONS

The Walter Rathbone Bacon Traveling Scholarship of the Smithsonian Institution granted to Dr. Alan Mozley for 1932 and 1933 for field studies of land and fresh-water mollusks in northern Asia, in order to correlate these with similar researches which he had made in the far north of North America, was extended for an additional season to permit the gathering of further data. This is the first report it has been possible to present on Dr. Mozley's later work.

Dr. Mozley intended to make a trip down the Lena River and to explore this stream and adjacent territory before attempting a final report, but for certain reasons it was not practicable for him to obtain the necessary permission for work in this territory. He therefore, with the sanction of the authorities of the Smithsonian Institution, shifted his field of exploration to Finland and northern Sweden, using Alvsky, Kabdalis, Östersund, Strömsund, Sveg, Orsa, Mora, Älvdalen, and Stockholm as bases for his quest.

At the close of the collecting season Dr. Mozley revisited England, where he continued museum studies of his catches, after which he

returned to the United States National Museum for his final endeavors. These are in part embodied in a paper entitled "The Fresh-Water and Terrestrial Mollusca of Northern Asia", published in the Transactions of the Royal Society of Edinburgh, vol. 58, pt. 3, no. 24, pp. 605–695, pls. 1–5, figs. 1–8, 1935–36. In this he describes the species collected by him and discusses their ecologic relationship.

The region embraced in this work includes the greater part of continental Asia north of latitude 50°, excepting outer Mongolia and Manchuria, and the Lake Baikal area with its peculiar fauna. In the region covered 67 species and subspecies were obtained and examined in detail. A certain number of forms are held in abeyance, to be discussed in a final report, upon the preparation of which Dr. Mozley is now engaged.

DR. BLACKWELDER'S STUDY OF THE STAPHYLINID FAUNA OF THE WEST INDIES

The Walter Rathbone Bacon Scholarship was awarded in June 1935 to Dr. Richard E. Blackwelder, of Stanford University, California. In his application for this scholarship the successful candidate indicated that his project should consist of a study of the staphylinid fauna of the West Indies, with especial reference to the subfamily Tachyporinae.

Accordingly Dr. Blackwelder set sail from New York late in June and commenced the field work necessary for the completion of the project. In succession he has visited the islands of Jamaica, Gaudeloupe, Hispaniola, Puerto Rico, Antigua, St. Thomas, Trinidad, Tobago, Grenada, Caracou, St. Vincent, Union, Barbados, St. Lucia, Martinique, Dominica, Montserrat, Antigua, and St. Kitts. Depending upon the size of the islands and the opportunities for collecting, Dr. Blackwelder has spent a longer or shorter time on each of these islands.

During the coming 6 months the islands of the Greater Antilles will be revisited, the second visit coming at a different time of year from the first, in that way making it possible to get species which were not found at the first attempt.

The results of his trip so far, as shown in his monthly reports, have been gratifying, many thousands of Staphylinidae having been already obtained, together with material in other groups of the animal kingdom. Material other than Staphylinidae has been of the Coleoptera, arachnids, diplopods, chilopods, and birds.

At the end of his field work in the West Indies it is intended that Dr. Blackwelder will return to Washington, there to prepare a series of the species which he has collected and which he will take to the British Museum for comparison with the types of described West Indian species. Upon his return from the British Museum Dr. Black-

welder will work over the entire collection and prepare a report upon this group of insects.

GRANTS

Kamerlingh Onnes Laboratorium der Rijks-Universiteit te Leiden.—In continuation of a number of previous grants to the Kamerlingh Onnes Laboratory, through its director, Prof. Dr. W. H. Keesom, the Institution contributed $500 toward the support of certain of the low-temperature researches now in progress at the laboratory. At the suggestion of the Secretary, a like contribution was also made by the Research Corporation of New York.

Dr. Erzsébet Kol.—A grant of $700 was made to Dr. Erzsébet Kol to enable her to study the biology of snow algae on the snow fields and glaciers of Alaska. Dr. Kol, a botanist of Szeged, Hungary, has come to this country through a fellowship from the American Association of University Women to study the snow algae on high mountains in the United States. The Smithsonian grant will enable her to extend the work to include Alaska. Dr. Kol's studies in the field of cryobiology have covered a period of 10 years and have included similar field work in the mountains of Switzerland, Norway, France, and Hungary.

Mount Washington Observatory.—A small contribution of $50 was made toward the continued support of Mount Washington Observatory. This high-level observatory (6,284 ft.) in New Hampshire is under direction of Dr. Charles F. Brooks, of the Harvard Blue Hill Meteorological Observatory. Its observations are at times the only upper air data available in the northeastern United States in periods of general storm or fog. All phases of ice formation on airplanes can readily be studied here on the ground, as the ice-forming wind rushes by at airplane speeds.

FIFTH ARTHUR LECTURE

The fifth Arthur Lecture was given in the auditorium of the National Museum February 25, 1936, by Dr. Earl S. Johnston, assistant director of the Division of Radiation and Organisms, Smithsonian Institution, under the title "Sun Rays and Plant Life." Dr. Johnston pointed out that the wide range in type of vegetation on the earth is due to the great variation in the solar energy reaching our planet. These variations relate to the duration, the intensity, and the quality or wave length of sunlight. The lecturer discussed the investigations by the Smithsonian Institution and other agencies of the harmful and beneficial effects upon plant growth of specific wave lengths of light.

The lecture will be published in the General Appendix to the 1936 Smithsonian Report.

SMITHSONIAN INSTITUTION EXHIBIT AT THE TEXAS CENTENNIAL EXPOSITION, DALLAS, TEX.

The Smithsonian Institution exhibit at the Texas Centennial Exposition June 6 to November 30, 1936, was concerned wholly with a presentation of the laboratory methods and processes involved in the preparation and restoration of a fossil dinosaur skeleton and with a picturization of the scientific knowledge of prehistoric reptilian life derived from laboratory studies. The exhibit formed one of a series of scientific exhibits entitled "The Story of Life", prepared by the combined efforts of the United States Public Health Service, the colleges and universities of Texas, and the Smithsonian Institution.

The Smithsonian Institution exhibit occupied a rectangular bay, the back wall of which was about 30 feet wide and the side walls of which were, roughly, 30 feet and 20 feet, respectively, in length. A railing prevented the visitors from approaching the rear wall closer than 15 feet and the side walls 3 feet. There was thus made available between the railing and the rear wall an area of approximately 15 feet by 30 feet for the carrying on of the regular laboratory work in plain view of the visitor. Here daily during the course of the exposition Norman H. Boss, chief preparator of the division of vertebrate paleontology in the National Museum, and an assistant, Gilbert Stucker, of Chicago, who was employed for the period of the exposition, carried on the intricate and varied work involved in working up in relief parts of the Jurassic dinosaur *Camarasaurus*.

On the back wall of the working area there was mounted a full-size line drawing of *Camarasaurus* and superposed on the drawing was the original skull and the first five vertebrae, which had been prepared in the National Museum laboratory prior to the exposition. These original parts, together with those gradually exposed by the preparators and the full-size profile drawing, gave the visitor a clear idea of the complicated nature of the preparatory work in this scientific field.

Five large masses of plaster-bandaged fossil in the rock, one weighing approximately 2½ tons and another 1½ tons, were shipped to Dallas and constituted the working material during the exposition. These masses are in the same form as received in 1923 by the United States National Museum from the Dinosaur National Monument quarry in Utah. The finished pieces were exhibited on available floor space in the working area of the exhibit.

Flanking the laboratory area there were exhibited two oil paintings 15 feet by 8 feet prepared by two Washington artists, Bruce Horsfall and Garnet W. Jex, respectively. The Jex painting portrays reptilian life in the Permian age of Texas. The Horsfall painting visualizes *Camarasaurus*, the fossil skeleton of which was being prepared, as he was supposed to have appeared in the flesh and in the environment of his time, namely, the Jurassic age. Both paintings were executed under the close supervision of C. W. Gilmore, curator of vertebrate paleontology in the National Museum, and are as scientifically correct in the topography, vegetation, and reptile restoration as can be done with oil paint and brush.

In addition to the oil painting on the right flanking wall of the area there was exhibited a well-executed diorama visualizing all known life of the Jurassic age. This yielded to the visitor an understanding of the reptilian associates of the *Camarasaurus* in Jurassic times and vividly indicated the swampy, moist character of the land area of that distant time.

Thus the visitor to the Smithsonian Institution exhibit at the Dallas exposition had revealed to him the manner in which the Division of Vertebrate Paleontology in the United States National Museum is acquiring scientific knowledge as to prehistoric life and utilizing that information in the advancement of knowledge.

SMITHSONIAN SCIENTIFIC SERIES

The Smithsonian Scientific Series, a set of 12 volumes written in popular style and profusely illustrated on the various branches of science covered by the Institution's research activities, was first put on the market in 1928. In entering into the agreement for the sale of this series, a departure from the normal free distribution of its publications, the Institution had two aims in view, namely, the wider diffusion of knowledge and the increase of its financial resources for the promotion of research. The books are published and sold by a private corporation of New York, the Smithsonian Institution Series, Inc., and the Institution receives a royalty on all sales.

As the series has not been mentioned in my annual reports for the past 2 years, it will be interesting to state the results of this enterprise up to the close of the fiscal year 1936. From 1928, when the first set was sold, to June 30, 1936, there have been sold a total of 12,917 sets. In royalties, the Institution has received to date in the neighborhood of $150,000, a definite proportion of which has been added to the Institution's permanent endowment, and the balance expended for the most pressing scientific investigations. As the sales of the series are continuing at an ever-increasing rate, the Institution's endow-

ment funds will eventually be substantially augmented, with a corresponding increase in the annual income for current researches.

William L. Abbott bequest.—Dr. William L. Abbott, associate in zoology since March 25, 1905, who had conducted and sponsored many field expeditions for the Institution, died April 2, 1936. Under the terms of Dr. Abbott's will, the Smithsonian Institution is to receive, in addition to any of his books and papers that they may desire, one-fifth of his residuary estate. According to advices from the executors of the estate, the Institution's share will be in the neighborhood of $100,000. This final expression of Dr. Abbott's friendship is very gratifying to the Institution, since he was one of its most valued collaborators and had contributed materially to the upbuilding of its biological and other collections.

Charles Dyke bequest.—In the will of Charles Dyke, probated in Corpus Christi, Tex., July 29, 1935, appears the following provision:

Item three: All the rest, residue, and remainder of my estate * * * I give, devise, and bequeath to the Smithsonian Institute of Washington, District of Columbia, to be used in founding and endowing a chair in some branch of the Institution, to be designated as the branch of financial research, whose purpose is to take steps to capitalize on any inventions, discoveries in research, or through whatever other project seems most feasible. The aim of this bequest is to enhance the endowment funds of this Institution to the highest degree practicable in opulence through the efforts of said chair of financial research.

The Dyke estate is to remain in the hands of the executor during the life of the first beneficiary, after which the legacy will be paid to the Institution. Advice has been received from Mr. Dyke's attorney that the present value of the property is about $15,000.

In the furtherance of its researches, the Institution sent out or took part in 15 expeditions to a number of foreign countries as well as to many localities in the United States. Dr. Charles W. Gilmore collected rare vertebrate fossils in Montana and Wyoming. Dr. Charles E. Resser studied the Cambrian rocks of the southern Appalachian Mountains. Dr. G. Arthur Cooper established stratigraphic correlations of Devonian rocks in the mid-western States and in New York State. Mark C. Bandy collected mineral specimens in the famous mineral localities of Chile. Gerrit S. Miller, Jr., studied the fauna of the Florida Keys, with particular reference to the mammals peculiar to that area. Dr. Doris M. Cochran investigated the amphibian life of Brazil. Dr. Waldo Schmitt, as a member of the Hancock Pacific Expedition to the west coast of Central and South

America and the Galapagos Islands, collected specimens of marine life. Capt. R. A. Bartlett led an expedition to the Arctic which studied and collected the interesting marine life of the coasts of Greenland. Dr. David C. Graham continued to collect specimens of the mammal, bird, and insect fauna of little-known areas of Szechwan, China.

Dr. Aleš Hrdlička continued his archeological excavations on Kodiak Island, Alaska. Neil M. Judd visited many of the antiquities of Mexico as a member of the United States delegation to the Seventh American Scientific Congress. Herbert W. Krieger studied the early Indian sites along the lower Potomac River in Maryland and Virginia. M. W. Stirling examined a number of ancient Maya sites in Central America. Dr. F. H. H. Roberts, Jr., continued his investigations of Folsom man in northern Colorado. Dr. Truman Michelson conducted Indian language studies of James and Hudson Bays, Canada.

PUBLICATIONS

The several series of publications issued by the Institution and its branches constitute its chief means of carrying on the "diffusion of knowledge among men", as stipulated by its founder, James Smithson. The majority of these publications are technical in character, but many others are in popular demand, notably the Smithsonian Annual Reports, which summarize scientific progress each year in 25 or 30 semi-popular articles by leading authorities; the bulletins of the Bureau of American Ethnology on various phases of the study of the Indians; and certain of the bulletins of the National Museum, such as Bent's volumes on life histories of North American birds. The wider diffusion of scientific information has been aided in recent years by a service of popular science news releases, based on the researches of the Institution, which are widely used by leading newspapers, and this year by a weekly radio program on Smithsonian activities put on the air by the United States Office of Education in cooperation with the Institution's editorial office.

It is gratifying to report that this year a portion of the printing appropriation has been restored, so that it has been possible to resume publication in a small way of the bulletins and proceedings of the National Museum and the bulletins of the Bureau of American Ethnology, all of which had been practically suspended for 3 years because of drastically reduced printing appropriations. This suspension overburdened the Smithsonian Miscellaneous Collections, a series supported by the limited private funds of the Institution, with many papers which would normally have appeared in the other series.

The titles, authors, size, and date of appearance of all publications issued during the year are listed in the editor's report, appen-

dix 10. It may be said here that a total of 70 volumes and pamphlets were published; 54 of these were issued by the Institution proper, 13 by the National Museum, and 3 by the Bureau of American Ethnology. The number of publications distributed was 124,359.

<div align="center">LIBRARY</div>

The Smithsonian library comprises 10 major and 35 minor units, which together contain a total of 860,000 volumes, pamphlets, and charts. The new accessions for the year numbered 11,215, most of these coming in exchange for the publications of the Institution and its branches. Outstanding among the accessions received were the semiprivate libraries of three of the members of the staff and associates of the Institution, namely, the invertebrate paleontology library of Dr. E. O. Ulrich, the collection of works on orthoptera of the late Dr. A. N. Caudell, and the anthropological library of the late Dr. Walter Hough. The routine work of the staff included cataloging 7,015 publications, preparing and filing 55,829 cards, entering 25,205 periodicals, and making 11,235 loans, of which 281 were to libraries outside the Smithsonian system. In addition, a large amount of cataloging and carding was accomplished in connection with the union catalog. The sorting, arranging, and labeling of the collection of thousands of miscellaneous items that had accumulated for years in the Smithsonian west stacks was practically finished, with the result that hundreds of needed publications were brought to light. It is significant in the growth of the library's usefulness that the staff was called on for even more reference and bibliographical service than usual, not only in connection with the Institution's own scientific work but also in response to inquiries from its correspondents throughout the country.

Respectfully submitted.

<div align="right">C. G. ABBOT, <i>Secretary.</i></div>

APPENDIX 1

REPORT ON THE UNITED STATES NATIONAL MUSEUM

Sir: I have the honor to submit the following report on the condition and operation of the United States National Museum for the fiscal year ended June 30, 1936:

Appropriations for the maintenance of the National Museum for the year totaled $760,742, which was $44,671 more than for 1935.

COLLECTIONS

Material added to the collections during the year embodied a great variety of valuable accessions, coming mostly as gifts from individuals interested in the Museum and from expeditions sponsored by the Smithsonian. A total of 486,581 specimens were received, comprising 1,784 separate accessions and distributed among the five departments as follows: Anthropology, 4,856; biology, 263,705; geology, 213,024; arts and industries, 2,281; and history, 2,715.

The more important of these accessions are summarized as follows:

Anthropology.—Outstanding among the ethnological material received in the department of anthropology were the large Richard K. Peck collection of weapons, costumes, and other articles illustrating the decorative arts of the Negritos and Papuans of Dutch New Guinea and of the Dyaks of Borneo; and specimens illustrating the culture of the Jivaro Indians of Ecuador. In North American material the Sioux, Hopi, and Navaho Indian tribes were represented. President Franklin D. Roosevelt presented a collection of costumes, musical instruments, and weapons from the Cuna and Tule Indians of southeastern Panama. There came also ethnologic artifacts from West and South Africa, Australia, China, and Japan. The noteworthy Virgil M. Hillyer collection of articles illustrating the history of lighting, with an endowment to the Smithsonian of $7,000, was presented by Mrs. Hillyer. Over 200 specimens were added to the collection of musical instruments.

Of special interest among the archeological material received were the following: 557 Paleolithic artifacts from Palestine collected by the 1934 joint expedition of the British School of Archeology in Palestine and the American School of Prehistoric Research; several lots of earthenware, stone, shell, and other artifacts from Alabama, Alaska,

Costa Rica, Puerto Rico; and over 1,100 archeological specimens from Kodiak Island, Alaska, collected by Dr. A. Hrdlička in 1934 and now cataloged.

Skeletal material comprised about 500 specimens, mostly from Kodiak Island and from prehistoric graves in Crimea.

Biology.—The Museum was singularly fortunate during the year in acquiring older biological collections containing many type specimens and otherwise important historical material that has served as a basis for monographic studies by recognized authorities. Also there was a marked increase in the number of species and genera acquired not heretofore represented in the Museum.

In mammals the outstanding addition was 465 specimens from Africa, Asia, and South America, representing approximately 300 forms not previously available in our collections. Important bird specimens (skins and skeletons), many of them types, came from Siam, Rhodesia, Puerto Rico, Colombia, Honduras, West Africa, and Chile. There was added, in particular, a skin of the South Trinidad petrel (*Pterodroma arminjoniana*), the first received in North America. The largest accession of amphibians and reptiles of the year comprised 1,600 specimens from several south-central States collected by Dr. C. E. Burt. The ichthyological collections were enlarged by over 3,300 specimens, the most important single one being a large sailfish caught off Cocos Island, Costa Rica, by President Franklin D. Roosevelt and presented by him. Large series of fishes came from the Amazon River, as well as a representative lot from Virginia. Noteworthy among the insect accessions may be mentioned the valuable Bovie collection of weevils received as a gift from L. L. Buchanan; the Beutenmüller collection of Cynipidae; 20,000 vials of ectoparasites of rodents received from the National Institute of Health; the Alan S. Nicolay collection of clerid beetles; 12,000 Chinese insects from the Rev. D. C. Graham; and about 44,000 miscellaneous insects. Over 11,000 marine invertebrates of many kinds were added, including types of a number of new species. The mollusks totaled over 50,000 specimens (including 13,135 collected by Dr. J. P. E. Morrison, of the Museum staff, during several excursions into Virginia, West Virginia, Maryland, and the Carolinas). Over 54,000 plant specimens were added from many sources, outstanding among which was the large cactus collection of the late David Griffiths.

Geology.—Important acquisitions in mineralogy were obtained, as in former years, through the income from the Canfield, Roebling, and Chamberlain funds. An outstanding collection of Chilean minerals, including what proved to be six new species, was made for the Canfield collection by Mark Bandy. The Roebling collection was enhanced by much new mineral material obtained from various

sources. Donated specimens and those received through exchange comprised many valuable minerals from many parts of the world.

The total number of distinct meteorite representatives in the collection was increased from 592 to 606 during the year. The most important accession to the petrological collection was a series of anorthosites, interesting rock types, from Norway.

In stratigraphic paleontology an important addition was about 100,000 specimens illustrating the Middle Devonian faunas of central New York, collected by Dr. G. A. Cooper a number of years ago and received in exchange from Colgate University. About 100,000 others, Middle Paleozoic rock specimens, came from Illinois, Indiana, Iowa, and Michigan.

Invertebrate fossils added represented Chile (Jurassic), Timor (Permian), Portugal (Ordovician), Oklahoma (Carboniferous), Florida (Miocene), and Hawaii (Pleistocene). The paleobotanical collections were enriched by rare types of fossil cones from the Cretaceous of Maryland and the Eocene of North Dakota.

Field expeditions in vertebrate paleontology yielded the following rarities: From Wyoming a nearly complete articulated skeleton of the mammal *Coryphodon*, so far as known the second entire specimen as yet found; from Montana articulated parts of the little-known dinosaur *Procheniosaurus*, fragments of *Leptoceratops*, and an adult skull of *Brachyceratops*. There were also added a nearly complete skeleton of the edentate mammal *Scelidodon capellini* from South America and the only known complete skull of the Oligocene lizard *Glyptosaurus giganteus*.

Arts and industries.—The outstanding accession in aeronautics was the airplane *Winnie Mae*, flown by Wiley Post and Harold Gatty, and subsequently by Post alone in various record flights, which was purchased through funds provided by a special Congressional appropriation. The airplane *Polar Star*, of exploration fame, used by Lincoln Ellsworth in the first flight across Antarctica in November and December 1935, in an expedition sponsored by the National Geographic Society, was received as a gift from Mr. Ellsworth. Propellers from the airships *Macon* and *Akron* were transferred from the Navy Department. The collection of scale models of aircraft was increased by 14 specimens, including models of the following: The Short Brothers' airplane of 1911; the Breguet sesquiplane *Point d'Interrogation*; the first plane built by Glenn Martin in 1909; a V–F–7–H; and the *Baby Clipper*.

In mechanical technology the most important accession was the original locomotive *Atlantic*, built at Baltimore in 1832, and the first locomotive to enter the National Capital. A Ford model T touring car of 1913, given by Harvey C. Locke, proved the most popular

transportation accession of the year. Two ship models were received from President Roosevelt: One of the R. M. S. *Mauretania* and the other of a modern seagoing trading junk of the island of Hainan, China. Capt. John B. Harrison presented two models of Chesapeake Bay vessels.

Other important specimens, to the number of 951, were added to the collection of textiles, organic chemistry, wood technology, history of agriculture, and medicine, as well as many valuable drawings, water colors, photographs, prints, and photographic and printing equipment to the division of graphic arts.

History.—Over 2,700 articles of historical and antiquarian value were received, many of them pertaining to the lives and careers of eminent Americans, such as Brand Whitlock, Maj. Gen. George A. Custer, Maj. Gen. Adolphus W. Greely, and Rear Admiral Winfield Scott Schley. Included also were 85 coins and 1,907 stamps for the numismatic and philatelic series.

EXPLORATIONS AND FIELD WORK

Work in a number of interesting fields of exploration was carried forward during the year, mainly through grants from the income of the invested funds of the Smithsonian Institution.

Anthropology.—Frank M. Setzler, acting head curator, investigated a large shell midden on St. Simons Island, Ga., at the request of the Society for Georgia Archeology; he also made surface surveys at other Georgia localities.

Under the joint auspices of the National Geographic Society and the Smithsonian Institution, H. B. Collins, Jr., assistant curator of ethnology, conducted archeological investigations of the prehistoric Eskimo at Cape Wales, Alaska, pursuant to previous studies at Bering Strait, St. Lawrence Island, and Point Barrow.

H. W. Krieger, curator of ethnology, spent brief periods in the study of aboriginal culture in tidewater Virginia and Maryland.

Dr. Aleš Hrdlička, curator of physical anthropology, spent the summer of 1935 on Kodiak Island, Alaska, excavating at the same site where he worked during previous years.

Biology.—Important biological work, supplementing that done in previous years by Dr. H. M. Smith, was carried on in Siam under a cooperative arrangement with H. G. Deignan, who forwarded a large shipment of birds and mammals.

W. M. Perrygo, taxidermist, assisted by Carleton Lingebach, collected birds and mammals in the Appalachian region, in an effort to obtain for the Museum representative specimens for geographic distribution studies.

Dr. A. Wetmore, assistant secretary, made two collecting excursions to White Top Mountain and one to Spruce Knob and other moun-

tains in West Virginia, and obtained specimens of use in outlining the local ranges of certain birds.

Dr. G. S. Myers, assistant curator of fishes, collected fishes in Dismal Swamp and the Chowan-Roanoke River systems, in connection with a survey of Virginia fresh-water fishes begun in 1933.

Under a grant from the Smithsonian Institution, the curator of mollusks, Dr. Paul Bartsch, began some breeding experiments with the mollusk *Goniobasis virginica* of the Potomac drainage, in an attempt to ascertain the effect of different environmental conditions on animals from the upper and lower parts of the river. Dr. J. P. E. Morrison on his own initiative collected mollusks for the Museum in the Blue Ridge and Shenandoah country.

Other biological field work included that of Austin H. Clark in a study of Virginia butterflies, in which he made a preliminary survey of 75 counties of the State; of P. W. Oman, who made an extensive collection (about 40,000 specimens) of Homoptera in the West; of E. P. Killip, who collected plants on the Florida Keys; of Dr. C. E. Burt, who continued his collecting for the Museum of herpetological specimens from the south-central States; and of Dr. R. E. Blackwelder, holder of the Walter Rathbone Bacon Traveling Scholarship of the Smithsonian Institution, who visited many of the islands of the West Indies in a study of staphylinid beetles.

Geology.—Mark C. Bandy spent four months in the Atacama Desert region of Chile in the interests of the Museum mineral collections in cooperation with Harvard University.

At the end of the year Assistant Curator E. P. Henderson was collecting in an extensive limestone contact zone on Prince of Wales Island, Alaska.

Dr. G. A. Cooper, stratigraphic paleontologist, made a number of field trips—to Virginia, Maryland, Pennsylvania, and New York, as well as the Midwest and Ontario—to obtain Middle Devonian rocks and other geological specimens.

Dr. C. E. Resser, curator of stratigraphic paleontology, spent two months in the southern Appalachians studying Cambrian geology.

The field explorations of vertebrate fossils under the direction of C. W. Gilmore begun last year were continued, and collections were made in the Two Medicine formation of Montana and the Wasatch of the Big Horn Basin, Wyo., with good results.

Late in the year Dr. C. L. Gazin headed an expedition into the vertebrate-fossil fields of New Mexico and Arizona.

MISCELLANEOUS

Visitors.—Visitors to the various Museum buildings during the year totaled 1,973,673, an increase of 135,981 over last year and over 44,000 more than has ever before been recorded for a single year. The

312,031 visitors during August 1935 is the largest ever recorded for a single month. The annual attendance in the several buildings was recorded as follows: Smithsonian Building, 312,896; Arts and Industries Building, 873,533; Natural History Building, 635,561; Aircraft Building, 151,683.

Publications.—A small increase in the Museum allotment for printing resulted in a corresponding increase in the number of papers published. Thirteen publications were issued—the Annual Report, 11 Proceedings papers, and 1 number of the Contributions from the National Herbarium. These are listed elsewhere in this report (appendix 10). Volumes and separates distributed during the year to libraries and individuals throughout the world aggregated 33,936 copies.

Under direction of the Museum editor, Paul H. Oehser, a sizable start has now been made on the long task of compiling the comprehensive index to Museum publications, now 3 years in progress. The index now comprises about 183,500 cards and is complete through Bulletin 47 (part 2) and Proceedings volume 17.

Assistance from work-relief agencies.—Under supervision of the curatorial staff of the Museum, a great deal of work was performed during the year by personnel assigned to the Museum by the Federal Art Project, the Federal Emergency Relief Administration, and the Works Progress Administration, the latter two through the District of Columbia Government. The work performed was chiefly as follows: Checking, labeling, and repairing library material, preparing drawings and photographs, typing, preparing and mounting specimens and miscellaneous work on them, model making and repairing, labeling and drafting, translating, and work on plaster casts. The work aggregated 28,572 man-hours.

Special exhibitions.—Fifteen special exhibitions were held during the year under the auspices of various scientific, educational, and Government agencies, including, among others, the Association of Federal Architects, Washington Philatelic Society, Center of Inter-American Studies of George Washington University, District of Columbia Dental Society, and Works Progress Administration.

Changes in organization and staff.—Through a reorganization of the fiscal offices of the Institution effective July 1, 1935, all fiscal work was coordinated under the direction of N. W. Dorsey, accountant and auditor. All fiscal matters pertaining to Museum appropriations are now handled through Thomas F. Clark, assistant accountant and auditor. Frank M. Setzler, assistant curator of archeology, was advanced to the position of curator of anthropology on December 16, 1935, and at the same time was named acting head curator of the department of anthropology. Paul S. Conger, of the Carnegie Insti-

tution of Washington, was appointed honorary custodian of diatoms on February 29, 1936.

Royal H. Trembly was advanced on November 16, 1935, from assistant superintendent to superintendent of buildings and labor, succeeding J. S. Goldsmith, retired; and on February 16, 1936, Charles C. Sinclair, senior mechanic, was promoted to assistant superintendent. Lawrence L. Oliver, assistant property clerk, was advanced on October 1, 1935, to the position of property clerk, succeeding the late W. A. Knowles; and Stephen C. Stuntz was transferred on November 1, 1935, from the Smithsonian library and made assistant property clerk. Floyd B. Kestner was appointed junior photographer on September 3, 1935; William E. Wade, undermechanic, was promoted on September 1, 1935, to succeed George H. Sherwood as assistant engineer; Joseph H. Boswell was transferred to the Museum from the National Gallery of Art guard force on December 9, 1935, to succeed H. G. Lugenbeel as principal guard in the Freer Gallery.

Carl W. Mitman, head curator of arts and industries, was designated as Smithsonian contact officer in connection with the Texas Centennial Exposition; and Norman H. Boss, chief preparator in vertebrate paleontology, as exhibits supervisor of this exhibit.

Ten Museum employees were transferred from the active to the retired list for age or disability during the year, as follows: Earl V. Shannon, assistant curator of physical and chemical geology, on July 31, 1935, through disability; James S. Goldsmith, superintendent of buildings and labor, on October 31, 1935, through age, after 53 years of service; George H. Sherwood, assistant engineer, through age, and William J. Sammond, assistant engineer, for disability, on August 31, 1935 and May 31, 1936, respectively; John M. Barrett, junior scientific aid, on February 29, 1936, through age, after $45\frac{1}{2}$ years of service; Harry G. Lugenbeel, sergeant of the Freer Gallery guard force, on October 12, 1935, through disability, after 42 years of service; John Hammerstrom, guard, through age, and Thomas N. Stanford, guard, through disability, on September 30 and November 29, 1935, respectively; and Mrs. Maria Ezell and Mrs. Maggie Johnson, of the char force, through disability.

Necrology.—The year was marked by the loss of several men long associated with the National Museum, including three active workers and four honorary staff members, as follows: Dr. Walter Hough, head curator of anthropology, who died on September 20, 1935, after almost 50 years of service; William A. Knowles, property clerk, who died on July 29, 1935, after 43 years of service; August Flegel, guard, on February 28, 1936, after 10 years of service; and, from the honorary staff, Dr. Albert Spear Hitchcock, custodian of grasses since October 10, 1912, who died on December 16, 1935; Andrew Nelson

Caudell, custodian of orthoptera since December 19, 1905, who died on March 1, 1936; Dr. William Louis Abbott, associate in zoology since March 25, 1905, who died on April 2, 1936; and Dr. August Frederick Foerste, associate in paleontology since September 1932, who died on April 23, 1936.

Respectfully submitted.

ALEXANDER WETMORE,
Assistant Secretary.

Dr. CHARLES G. ABBOT,
Secretary, Smithsonian Institution.

APPENDIX 2

REPORT ON THE NATIONAL GALLERY OF ART

Sir: I have the honor to submit the following report on the activities of the National Gallery of Art for the fiscal year ended June 30, 1936:

In the last 12 months much of the business of the Gallery has related to the care, protection, and restoration of paintings in the possession of the Government. Six were cleaned, relined, and restored for the United States National Museum. Forty-nine of the paintings in the White House were cleaned, varnished, and protected; one was mounted on masonite. The Harriet Lane Johnston paintings in the Gallery were all cleaned, varnished, and covered at the back with sisal kraft paper. Three of these were cleaned of varnish and carefully restored.

An air-conditioning unit for humidity and temperature control has been installed in the storage workroom. The temperature is maintained at from 70° to 78°, and the relative humidity is held to a variation of about 20 percent, from 50 to 70 percent, which is a great improvement over the conditions outside. In addition to the better preservation of our paintings and works of art, it would seem that the conditioned temperature and humidity would reduce the formation of mold and the activity of insects.

APPROPRIATIONS

For the administration of the National Gallery of Art by the Smithsonian Institution, including compensation of necessary employees, purchase of books of reference and periodicals, traveling expenses, uniforms for guards, and necessary incidental expenses, $34,275.00 was appropriated, of which $16,153.34 was expended for the care and maintenance of the Freer Gallery of Art, a unit of the National Gallery.

THE NATIONAL GALLERY OF ART COMMISSION

The fifteenth annual meeting of the National Gallery of Art Commission was held at the Smithsonian Institution on December 10, 1935. The members present were: Frank Jewett Mather, Jr., vice chairman; Dr. Charles G. Abbot (ex officio), secretary; and Herbert Adams,

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Gifford Beal, Charles L. Borie, Jr., Frederick P. Keppel, John E. Lodge, Paul Manship, George B. McClellan, Charles Moore, Edward W. Redfield, and Mahonri M. Young. Ruel P. Tolman, curator of the division of graphic arts in the United States National Museum and acting director of the National Gallery of Art, was also present.

In response to a resolution adopted at the last meeting, a report on the future of the National Gallery of Art was presented by the executive committee.

The available sites for a National Gallery of Art and the announced plans of Andrew W. Mellon were discussed.

The death of Joseph H. Gest, chairman of the Commission, on June 26, 1935, was announced, and resolutions, submitted by Dr. Abbot, were adopted.

The following officers were elected for the ensuing year: Charles L. Borie, Jr., chairman; Frank Jewett Mather, Jr., vice chairman; and Dr. Charles G. Abbot, secretary; as well as the members of the executive committee: Charles Moore, Herbert Adams, and George B. McClellan. Charles L. Borie, Jr., as chairman of the Commission, and Dr. Charles G. Abbot, as secretary of the Commission, are ex officio members.

The Commission recommended to the Board of Regents the re-election for the succeeding term of 4 years of the following members: James E. Fraser, Frank J. Mather, Jr., and Edmund C. Tarbell.

Messrs. Borie, Keppel, and Young were appointed to suggest the names of three persons from which the Commission should select one for recommendation to the Board of Regents to fill the vacancy caused by the death of Joseph Gest.

The Commission viewed certain works of art offered to the Gallery within the year, and selected the following:

Portrait of Hon. John B. Henderson and portrait of Mrs. Henderson (Mary Newton Foote Henderson), by Jean Joseph Benjamin-Constant (1845–1902). Gift of the heirs of Mrs. Mary F. Henderson through Dr. Moore. (Accepted for the National Portrait Gallery.)

Portrait of His Majesty King George V of Great Britain, by Frank O. Salisbury. Presented to President Roosevelt for the American Nation by the artist. (Accepted for the National Portrait Gallery.)

A plaque of Francis Davis Millet (1846–1912), by Augustus St. Gaudens. Gift of Ernst G. Fischer.

A collection of 497 intaglio prints by members of the Chicago Society of Etchers. Gift of the Chicago Society of Etchers, through the president, Lee Sturgis, the executive board of the society, and Mrs. Bertha E. Jaques, its secretary-treasurer.

A collection of 47 fans. Gift of the estate of Virginia Woodbury Lowery Brunetti, Duchess of Arcos, deceased.

Four dry-points: "Antarctica", "The Rivals", "Twilight of the Gods", and "Scouts"; and two etchings: "Birds of the Sea" and "Witches' Sabbath à la Mode", by Paul F. Berdanier, Sr. Gift of the artist.

"Kayser's Pond" (Maine), by J. B. Bristol, N. A. Bequeathed to the United States National Museum by Martha L. Loomis, late of Framingham, Mass. Transferred to the National Gallery of Art.

THE CATHERINE WALDEN MYER FUND

One English and three Early American miniatures were acquired from the fund established through the bequest of the late Catherine Walden Myer, "for the purchase of first-class works of art for the use and benefit of the National Gallery of Art", as follows:

"Portrait of a Man", by Benjamin Trott (about 1770–1839); from Mrs. Alba D. Walling, Boston, Mass.

"A Colonial Gentleman", by artist undetermined; from Mrs. Wells Peckham (Mrs. Elliott Peckham), Washington, D. C.

"Portrait of a Man", by Robert Field (about 1769–1819), and "Portrait of a Man, I H", artist undetermined; from Miss M. V. Stiles, Savannah, Ga.

LOANS ACCEPTED BY THE GALLERY

Portrait (three-quarter length) of Dr. Charles Greeley Abbot, Secretary of the Smithsonian Institution, by Nicholas R. Brewer, 1935. Lent by the artist.

Portrait of the Honorable Charles Evans Hughes, Chief Justice of the United States and Chancellor of the Smithsonian Institution, by George Burroughs Torrey, 1935. Lent by Chief Justice Hughes.

Plaster bas-relief portrait of Honorable Charles Evans Hughes, by Harry Lewis Raul. Lent by Chief Justice Hughes.

LOANS BY THE GALLERY

The portraits of Cardinal Desire Joseph Mercier, Admiral Sir David Beatty, and Premier Georges Clemenceau, by Cecilia Beaux, N. A., leaders in the World War, from the National Art Committee collection for the National Portrait Gallery, were lent to the American Academy of Arts and Letters, New York City, for an exhibition from November 15, 1935, to May 1, 1936, of the works of Miss Beaux. Two were returned, and the portrait of Premier Georges Clemenceau was shipped from New York directly to the Texas Centennial Exposition.

A selection of nine paintings from the William T. Evans and other collections were lent to the Virginia Museum of Fine Arts, Richmond, to be shown in the inaugural exhibition of that museum from January 18 to March 1, 1936, as follows: "Villa Malta", by Sanford R. Gifford; "Aurora Borealis", by Frederic E. Church; "High Cliff, Coast of Maine", by Winslow Homer; "September Afternoon", by George Inness; "November", by Dwight Tryon; "The Cup of Death", by Elihu Vedder; "Water Lilies", by Walter Shir-

law; "Fired On", by Frederic Remington; "The Mirror", by Robert Reid. These paintings were returned to the Gallery March 2, 1936.

Five portraits which were lent to the Public Library of the District of Columbia for exhibition in the central library on June 18, 1935, were returned February 28, 1936. They are: "John Tyler", by George P. A. Healy; "A Lady", by Gilbert Stuart; "Col. Robert Charles Wetmore", by Henry Inman; "Andrew Jackson", by Rembrandt Peale; "Commodore Stephen Decatur", by Gilbert Stuart.

Three portraits and two subject-paintings were lent to the Public Library of the District of Columbia for exhibition in the central library on February 28, 1936, and are still in its custody at the close of the fiscal year. They are: "Portrait of Henry B. Fuller", by George Fuller; "Portrait of Jessie J. Burge", by Abbott H. Thayer; "Portrait of Wyatt Eaton", by J. Alden Weir; "The Visit of the Mistress", by Winslow Homer; "Moonlight", by Albert P. Ryder.

The Procurement Division of the United States Treasury, through Robert LeFevre, on April 24, 1936, borrowed, with the consent of their owner, William Kemeys, of Garrett Park, Md., two pieces of sculpture by Edward Kemeys: "Buffalo and Wolves" (bronze) and "Jaguar and Peccary" (plaster). They are now in the small meeting room in the Connecting Building, Constitution Avenue.

The painting by John La Farge entitled "Visit of Nicodemus to Christ" was lent to the Metropolitan Museum of Art, New York City, for an exhibition of the work of John La Farge from March 23 to April 26, 1936. This was returned to the Gallery on May 1, 1936.

The "Portrait of Walter Shirlaw", by Frank Duveneck, was lent to the Cincinnati Museum of Art, Cincinnati, Ohio, for an exhibition of the works of Duveneck from May 22 to June 21, 1936. Owing to the local interest shown in the work of this Ohio painter, permission was granted to extend the exhibition through September 7.

The painting "Fired On", by Frederic Remington, and the "Portrait of Premier Georges Clemenceau", by Cecilia Beaux, have been lent to The Dallas Museum of Fine Arts for exhibition at the Texas Centennial Exposition, 1936, Dallas, Tex., from June 6 to November 29, 1936; also two small bronzes by Edward Kemeys, "Bear" and "Coyote" from the Kemeys loan collection, with permission of their owner, William Kemeys.

The painting entitled "The Moose Chase", by George DeForest Brush, has been lent, through the Carnegie Public Library at Fort Worth, Tex., to the Fort Worth Frontier Centennial Exposition, being held at Fort Worth from July 1 to November 30, 1936.

WITHDRAWALS BY OWNERS

The four large portraits, George Washington, Andrew Jackson, Henry Clay, and W. W. Corcoran, lent to the Gallery through Chief

Justice J. Harry Covington in January 1917, during reconstruction of the Court building, were returned to the Supreme Court of the District of Columbia through Chief Justice Alfred A. Wheat in September 1935.

Walter A. Swinney, of Baltimore, Md., on August 1, 1935, withdrew his painting, The Holy Family, which had been in the care of the Gallery since February 1920.

The self portrait by George Catlin was returned on October 17, 1935, to Miss Mary Cogswell Kinney, of New York City, granddaughter of the subject, who lent it in July 1933.

An oil painting, On the Lido, Venice, by H. Corrodi, Rome, received in October 1927, was, on October 22, 1935, delivered, by direction of the owner, Mrs. Arthur T. Brice, to the Women's National Democratic Club, Washington, D. C.

Two early American portraits by Thomas Sully (1783–1872) of Mr. and Mrs. John Crathorne Montgomery, lent by Mrs. Mary Montgomery Norton in 1932, were, by authorization of Mrs. Norton, withdrawn on November 8, 1935, by Mr. Robert Montgomery, of Villanova, Pa.

The large painting by George DeForest Brush, Indian Burial, lent to the Gallery in July 1931 by Mr. and Mrs. Brush, was withdrawn by them on June 9, 1936.

The plaster death mask of Napoleon, signed Antommarchi, lent to the Gallery in April 1927 by Mrs. Louise Rochon Hoover, of Washington, D. C., was withdrawn by Mrs. Hoover in January 1936.

Eleven paintings and one marble, received as a loan in 1910 from the Duchess de Arcos, were withdrawn by her estate on February 18, 1936.

SPECIAL EXHIBITIONS

Eight exhibitions were held, as follows:

September 19 to October 6, 1935.—Exhibition of national and international high school art, sponsored by the American Federation of Arts and Scholastic, the American High School Weekly. Invitations to an informal opening and an illustrated catalog contained in a special number of Scholastic were issued by the sponsors.

October 18 to November 14, 1935.—Exhibition of 497 intaglio prints, etchings, engravings, and drypoints, executed by members of the Chicago Society of Etchers; offered as a gift to the Gallery by the president, Lee Sturgis, the executive board of the society, and Mrs. Bertha E. Jaques, its secretary-treasurer. Cards were issued by the Gallery; each print was labeled in lieu of a catalog.

December 5, 1935, to January 5, 1936.—Exhibition of miniatures (53) by members of the American Society of Miniature Painters, New York City, under the auspices of that society and Mrs. Elsie Dodge

Pattee, president. Cards were issued by the Gallery; each item was labeled in lieu of a catalog.

February 5 to 29, 1936.—Exhibition of pastels, water colors, etchings, drawings, and lithographs (70) by Mons Breidvik, Norwegian artist, of New York City. Cards were issued by the Gallery to an opening view, and the artist provided a small folder catalog.

February 5 to 29, 1936.—An exhibition of portraits (37) by Bjorn P. Egeli, of Washington, D. C. Cards to an opening view were issued by the Gallery, and the artist provided a folder catalog.

February 5 to 29, 1936.—Exhibition of vitreous enamels (six specimens) by Frances and Richard MacGraw, of New York and Washington. Cards to the opening view were issued by the Gallery; there was no catalog, labels telling the story.

April 8 to 29, 1936.—Exhibition of the First Annual Metropolitan State Art Contest, 1936; under the auspices of the Department of Fine Arts of the District of Columbia Federation of Women's Clubs, Mrs. Samuel A. Swiggett, chairman, cooperating with the following seven Washington art organizations: The Arts Club; the League of American Pen Women; Miniature Society; Society of Washington Artists; Washington Landscape Club; Washington Society of Etchers; Washington Water Color Club; and a free-lance group. There were 339 exhibits, prints, paintings, and sculpture, by 170 artists; all were labeled. Cards were issued by the Gallery to an opening view.

June 10 to 30, 1936.—An exhibition of paintings, the work of children receiving free art instruction in 240 settlement houses and social agencies in the New York area, under the auspices of the Federal Art Project of the Works Progress Administration.

THE NATIONAL GALLERY REFERENCE LIBRARY

The library has been increased materially by numerous gifts and purchases. Miss Helen G. Rankin was temporarily employed as librarian.

SPECIAL DETAILS

The Acting Director was detailed from November 13 to 18, 1935, to attend the opening of the Cecilia Beaux exhibition at the gallery of the Society of Arts and Letters, New York City, and to study the art collections and methods of exhibiting in various art institutions, including the Morgan Library, the Museum of Modern Art, the Roerich Museum, the Museum of the City of New York, the Brooklyn Museum of Arts and Sciences, and the Metropolitan Museum of Art; and in Philadelphia, at the Pennsylvania Academy of the Fine Arts, the exhibit of contemporary American miniatures and water colors.

A second detail from February 6 to 9, 1936, was granted to visit the new Art Museum at Richmond, Va., as well as the Art Academy and the Valentine's Museum, but the real occasion of this trip was to study the 300 or more American miniatures assembled in the Gibbes Memorial Art Gallery at Charleston, S. C. This is one of a series of exhibitions of Early American miniatures which this gallery has brought together in the last few years. These exhibitions have been the means of discovering the names of artists not known before as well as much new information about others.

PUBLICATIONS

TOLMAN, R. P. Report on the National Gallery of Art for the year ending June 30, 1935. Appendix 2, Report of the Secretary of the Smithsonian Institution for the year ending June 30, 1935, pp. 24–30.

LODGE, J. E. Report on the Freer Gallery of Art for the year ending June 30, 1935. Appendix 3, Report of the Secretary of the Smithsonian Institution for the year ending June 30, 1935, pp. 31–34, pls. 1–2.

CATALOG: Smithsonian Institution, National Gallery of Art, Washington, D. C. Catalogue of the Works of Mons Breidvik, February 5 to 29, 1936. Folder of 4 pp. Privately printed.

CATALOG: Smithsonian Institute[ion], National Gallery of Art, Washington, D. C. Portraits by Bjorn Egeli, February 5–29, 1936. Folder of 4 pp. Privately printed.

CATALOG: Scholastic Art Exhibition. Illustrated Catalog of the Eighth Annual High School Art Exhibition, April 23 to May 12, Carnegie Galleries, 1935 (National Gallery of Art, U. S. National Museum, September 19 to October 6, 1935), pp. 1–16. Privately printed.

Respectfully submitted.

R. P. TOLMAN, *Acting Director.*

Dr. C. G. ABBOT,
Secretary, Smithsonian Institution.

APPENDIX 3

REPORT ON THE FREER GALLERY OF ART

SIR: I have the honor to submit the sixteenth annual report on the Freer Gallery of Art for the year ended June 30, 1936:

THE COLLECTIONS

Additions to the collections by purchase are as follows:

BRASS

36.7.   Persian, dated A. H. 607 (A. D. 1210). A pen-box; dark gray patina. The decoration is inlaid in silver and includes inscriptions in *naskhi* script embellished with human and animal heads. 0.050 by 0.314 by 0.064. (Illustrated.)
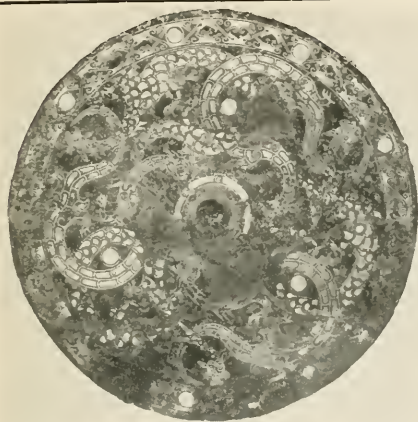
BRONZE

35.21–35.22.   Chinese, early Chou dynasty. A pair of tigers. White bronze with an even green patina and traces of earth adhesions. Decoration in low relief.
>   .21.   Length, 0.752, height, 0.252 over all, weight, 48½ lbs.
>   .22.   Length, 0.759, height, 0.251 over all, weight, 53½ lbs.
>   (Illustrated.)

36.3.   Chinese, earlier than the Han dynasty. A mirror-back. Dull brown patina with areas of green aerugo and earthy incrustation. Decorated with a design of dragons, inlaid in gold and silver. Diameter, 0.195. (Illustrated.)

36.4.   Chinese, Han dynasty; dated in correspondence with A. D. 202. A mirror. Shiny black patina and occasional spots of light green aerugo. The back is decorated with figures of cosmic deities and symbols in high relief. Inscription. Diameter, 0.134. (Illustrated.)

36.6.   Chinese, Chou dynasty. A ceremonial covered vessel of the type *huo*, in the form of an elephant; with a second elephant in miniature on the cover. Light apple-green patina. The surface is ornamented with formalized designs in low relief. 0.172 by 0.212 by 0.106 over all. (Illustrated.)

MANUSCRIPT

36.9–36.12.   Persian, sixteenth century. Four leaves from a manuscript book of *Yūsuf u-Zulaikhā* by Jāmī. Each leaf of manuscript is inlaid in a larger leaf of colored paper upon which border-designs of animals, birds, plants, and rocks, or of floral scrolls, are executed in gold. 0.252 by 0.150 over all.

PAINTING

36.1.   Indian, Mughal-Rājput, seventeenth century. Two ladies attended by serving women and musicians seated under a flowering locust tree. Delicate colors and gold on paper. 0.216 by 0.146.

PLATE 1

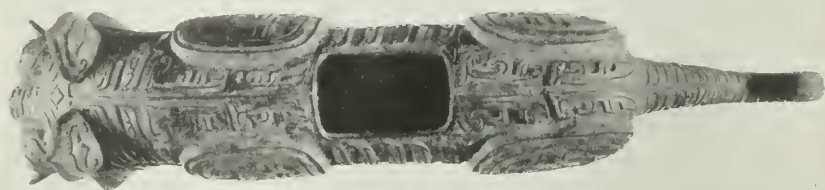36.3

36.4

36.5

36.7

SOME RECENT ADDITIONS TO THE COLLECTIONS OF THE FREER GALLERY OF ART

PLATE 2

35.22

36.6

35.22

SOME RECENT ADDITIONS TO THE COLLECTIONS OF THE FREER GALLERY OF ART.

36.14. Indian, Mughal, seventeenth century. Prince Dārā Shikoh and two musicians visiting the ascetic Kamāl. Color and gold on paper. 0.254 by 0.147.

35.23–35.24. Persian, Mongol period, early fourteenth century. Two illustrations from a manuscript book of the *Shāh-nāma* of Firdausi. Full color and gold on paper:
.23. Alexander and the Talking Tree. 0.242 by 0.285.
.24. Bahrām Gūr in the treasure vault of golden animals filled with jewels. 0.208 by 0.285.

35.25. Persian, Ṣafawī period, sixteenth century. A woman in a green coat. Color and gold on paper, 0.200 by 0.141.

36.8. Persian, Mongol period, early fourteenth century. School of Tabrīz. Illustration from the *Jāmi 'ut-Tawārīkh* by Rashīd ud-Dīn: A parley between two groups of Moslem horsemen. Color and gold on paper, 0.131 by 0.226.

POTTERY

36.13. Chinese, Sung dynasty. *Kuan yao:* a cup with foliate edge; low foot with thin brown rim (chipped). Dense, hard clay; lustrous green-gray glaze. 0.039 by 0.084.

36.2. Syro-Egyptian, eleventh–twelfth century. A bowl, intact. Soft, sandy clay; brownish-cream glaze (crazed). The decoration, painted in gold luster with ruby reflections, is made up of the words for felicity, pleasure, and wealth executed in an ornamental Kufic script. 0.089 by 0.210.

SCULPTURE

36.5. Persian (Daghestan), twelfth–thirteenth century (?). Semicircular pediment (broken in two and repaired) from above a double window. Decoration of animals and plants in moderately high countersunk relief. Gray limestone. 0.785 by 1.320 by 0.165. (Illustrated.)

Curatorial work has largely consisted in the study of Chinese, Japanese, Armenian, Arabic, Persian, and East Indian objects in the collection, of the texts and seals associated with them, and in the preparation of this material for Gallery records. Much time has been devoted, also, to the examination of objects submitted to the Curator for expert opinion as to provenance, age, meaning, or other significance. Written or oral reports on these objects were made to the institutions or private owners who asked for this service. Six hundred and seventy-three objects, 225 photographs of objects, and 18 inscriptions for translation were dealt with in this way.

Changes in exhibition have involved a total of 99 objects, as follows:

Bronzes, Chinese _____ 19
Paintings:
    American _____ 42
    Chinese _____ 6
    Japanese_____ 20
    Persian_____ 11
Sculpture, Persian_____ 1

ATTENDANCE

The Gallery has been open to the public every day from 9 until 4:30 o'clock, with the exception of Mondays, Christmas Day, and New Year's Day.

The total attendance of visitors coming in at the main entrance was 123,418. The total attendance for weekdays, exclusive of Mondays, was 85,697; for Sundays, 37,721. The average weekday attendance was 329; the average Sunday attendance, 725. The highest monthly attendance was reached in April (21,807) and August (13,919). The lowest monthly attendance was in December (5,460).

The total attendance of visitors on Mondays, by the south entrance, was 99, making a grand total attendance of 123,517.

There were 1,942 visitors to the offices during the year. The purposes of their visits were as follows:

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For general information_____ 346
To see objects in storage_____ 545
        Far Eastern paintings_____ 134
        Near Eastern paintings and manuscripts_____   3
        Indian paintings and manuscripts_____   4
        American paintings_____ 184
        Whistler etchings _____  14
        American pottery_____   2
        Oriental pottery, bronzes, jades, sculptures_____ 158
        Washington Manuscripts_____  46
To examine building and installation_____  23
To read in the library_____ 235
To make tracings and sketches from library books_____  11
To obtain permission to photograph or sketch_____  24
To examine or purchase photographs_____ 365
To submit objects for examination_____ 153
To see members of the staff_____ 240
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LECTURES

A course of four lectures on Persian Painting was given by Eustache de Lorey, former Director of the French Institute of Arts and Archaeology, Damascus, Syria, as follows:

Wednesday, March 11:
    Firdausi, Inspirer of Art.
Thursday, March 12:
    Islam and China.
Friday, March 13:
    The Height of Persian Miniature Painting, XV Century.
Saturday, March 14:
    Behzad, the Great Painter of the Persian Renaissance.

The total attendance at these lectures was 634.

Nineteen lectures and illustrated talks were given by members of the staff—at Columbia University and at the Gallery.

DOCENT SERVICE

Ninety-six groups ranging from 1 to 41 persons (total 413) were given docent service in the exhibition galleries upon request (of these 19 groups, totaling 23 persons, came on Mondays). Thirteen groups, totaling 193 persons, were given instruction in Chinese and Japanese arts in the study rooms.

PERSONNEL

Grace T. Whitney worked intermittently at the Gallery between October 7, 1935, and June 24, 1936, on the translation of Persian and Arabic texts.

Frank West, laborer, died on October 26, 1935.

Grace Aasen Parler, librarian, resigned her position on December 16, 1935.

Elizabeth Hill, who first reported for duty on November 11, 1935, was appointed librarian on December 17, 1935.

Harry G. Lugenbeel, sergeant, who had served the Gallery faithfully and efficiently since December 6, 1921, retired on October 12, 1935. He was succeeded by Joseph H. Boswell, whose appointment as sergeant was made on December 9, 1935.

Respectfully submitted.

J. E. LODGE, *Curator.*

Dr. C. G. ABBOT,
  Secretary, Smithsonian Institution.

APPENDIX 4

REPORT ON THE BUREAU OF AMERICAN ETHNOLOGY

SIR: I have the honor to submit the following report on the field researches, office work, and other operations of the Bureau of American Ethnology during the fiscal year ended June 30, 1936, conducted in accordance with the act of Congress of February 2, 1935. The act referred to contains the following item:

American ethnology: For continuing ethnological researches among the American Indians and the natives of Hawaii, the excavation and preservation of archeologic remains under the direction of the Smithsonian Institution, including necessary employees, the preparation of manuscripts, drawings, and illustrations, the purchase of books and periodicals, and traveling expenses, $58,730.00.

SYSTEMATIC RESEARCHES

At the beginning of the fiscal year M. W. Stirling, Chief of the Bureau, was in southern Florida for the purpose of locating archeological sites which it was anticipated would be excavated later in the year with relief labor. Mr. Stirling returned to Washington the latter part of July. In December two Works Progress Administration archeological projects having been approved on request of the Florida State Archaeological Survey in cooperation with the Smithsonian Institution, Mr. Stirling again went to Florida in order to consult with Works Progress Administration officials and supervise the establishing of the projects in Hillsborough and Dade Counties. He returned to Washington December 22. During the visit of a Blackfeet Indian delegation to Washington in the month of March 1936 opportunity was taken to make further checks and modifications on the sign language material of the late Gen. Hugh L. Scott.

Dr. John R. Swanton, ethnologist, devoted the greater part of his time during the first half of the fiscal year to the arrangement of the Timucua linguistic material under stems. Further material was added to his large paper on the Indians of the Southeast. On December 26, 1935, Dr. Swanton was appointed by the President a member of a commission of seven "to study and report to the next session of Congress its recommendations for a suitable celebration of the four-hundredth anniversary of the expedition of Hernando de Soto."

A later act of Congress extends the time within which the report may be made to January 2, 1939. Since this appointment was made, the activities of the Commission have absorbed a great deal of his time, involving as they do the promotion of research in foreign depositories of manuscripts, particularly those of Spain, the translation of Spanish works, and especially a study and determination, as far as that is possible, of the route taken by the great explorer and his successor, Moscoso, through territories now covered by 10 States of the Union. This involves the use of library materials and direct study in the field. At the request of the other members of the Commission, Dr. Swanton acted in the capacity of temporary chairman in arranging the first meeting, March 5 to 7, in the Smithsonian Building. At this meeting Dr. Swanton accepted the permanent chairmanship of the Commission, with the understanding, however, that he was to serve only until the factual report is made. A second meeting was held at Tampa, Fla., on May 4 to 6. After this was over, he accompanied Col. J. R. Fordyce, vice-chairman of the Commission, in an investigation of parts of the route of De Soto between Florida and Mississippi, and May 30 to June 18 he made a second expedition to examine that section between South Carolina and the Mississippi River.

During the year an interesting and ethnologically important letter bearing on the Indians of Florida was brought to Dr. Swanton's attention by Dr. Lucy L. Wenhold, of Salem College, Winston-Salem, N. C. A negative photostat of this document is also in the possession of the Florida State Historical Society, which has kindly loaned the use of it in making a positive copy, and this is being prepared for publication in the Smithsonian Miscellaneous Collections with annotations by Dr. Swanton and Dr. Wenhold.

On July 3, 1935, Dr. Truman Michelson, ethnologist, started on an expedition to the region of James and Hudson Bays, made possible by a subvention from the American Council of Learned Societies. The object was to make a linguistic map of this area. He spent some weeks at Moose Factory, about 10 days at the Great Whale River, a little over 2 weeks at Fort George, and a day at Rupert's House, and returned to Washington September 20. Besides getting data from the Indians and Eskimos of these places, he was able to get in contact with one Indian from the East Main River, one Cree from Wenusk, on the west side of Hudson Bay, one Cree from the Albany River, who had also been at Attawapiskat, and one Ojibwa from the Albany River. Data from some of the more remote localities were obtained by indirect means. His observations indicate that the folklore and mythology of these northern tribes are far closer to those of the Central Algonquian tribes than is usually thought.

On June 5, under a new grant from the American Council of Learned Societies, Dr. Michelson left Washington to renew his studies among the Indians and Eskimos of the James and Hudson Bays region.

The entire fiscal year was spent by Dr. John P. Harrington, ethnologist, in study of the Mission Indians of California, compiling complete notes for the forthcoming edition of the Boscana manuscript of 1882, which tells in 15 chapters of the life and religion of these Indians. This important manuscript of the early Franciscan Father Boscana, a missionary born in Catalonia, Spain, and stationed for years among the Mission Indians, was recently discovered by Dr. Harrington and a literal English translation of it without notes has already been published.

As a byproduct of the preparation of these notes an interesting account of the ethnology of the Mission Indians has been assembled, covering their mode of life, dress, food, sociology, religion, language, and knowledge of nature. The presence of Mission Indians in Washington has constantly enhanced and perfected this work throughout the fiscal year.

At the beginning of the year Dr. F. H. H. Roberts, Jr., archeologist, was engaged in excavations at the Lindenmeier site north of Fort Collins, Colo. This work was continued until September 10. The Lindenmeier site is the location where the first series of stone implements definitely attributable to the Folsom complex, the oldest established horizon in the archeology of North America, was found in the autumn of 1934. The investigations of the 1935 season were a continuation of those begun the preceding fall and consisted of intensive excavation of certain portions of the site. The digging brought forth additional information which makes possible the drawing of more detailed conclusions on the material culture of Folsom man.

When the summer's project was brought to a close Dr. Roberts went to Globe, Ariz., at the request of the authorities at Gila Pueblo, for the purpose of conferring with members of the staff on the finds which they had made at Snaketown, a Hohokam site, near Phoenix. He also studied the collections in the Gila Pueblo Museum and visited the Snaketown site and Casa Grande. The latter was the scene of considerable activity on the part of Cosmos Mindeleff and Dr. J. Walter Fewkes, members of the staff of the Bureau of American Ethnology, 40 and more years ago. Dr. Roberts returned to Washington October 1.

In January he took part, by special invitation, in a symposium on Early Man in America which was held at the annual meeting of the Society of American Naturalists at St. Louis. He also prepared a manuscript detailing the work done during the summer. This report,

Additional Information on the Folsom Complex: Report on the Second Season's Investigations at the Lindenmeier Site in Northern Colorado, was issued on June 30 as Smithsonian Miscellaneous Collections, vol. 95, no. 10.

Dr. Roberts left Washington June 1 for Anderson, Iowa, to inspect a site where Folsom points and other material had been found. This proved to be a highly interesting place, as it marks the easternmost locality that the true or High Plains form of the Folsom point has been noted. While in Iowa he saw and studied numerous collections of specimens and found evidence of the Folsom complex at a number of sites. From Iowa he proceeded to Colorado, where he resumed excavations at the Lindenmeier site. By the end of the year, June 30, several trenches had been run through portions of the site and an area 20 by 30 feet had been completely cleared of the several feet of accumulated earth which had covered it. This area consisted of an old occupation level upon which the traces of Folsom man and his activities were numerous.

From July 1935 to January 1936 Dr. W. D. Strong, anthropologist, served as consultant in anthropology to the Bureau of Indian Affairs. In addition to office work in relation to numerous acculturation studies being made on various Indian reservations of the United States, Dr. Strong made two field trips to various reservations and administrative centers in New Mexico and Arizona in August and December, respectively. In November a trip of several weeks was made to the Chippewa reservations in Minnesota to advise on problems of tribal reorganization. On January 5, 1936, Dr. Strong left Washington for Honduras as leader of a joint archeological expedition from the Bureau of American Ethnology, Smithsonian Institution, and the Peabody Museum, Harvard University. He was assisted in the field by Alfred Kidder, II, and Drexel A. Paul, Jr., from the Peabody Museum. Establishing its base at Progreso, in the Ulua Valley, the expedition made stratigraphic excavations at several sites on the Ulua River. In March and April Dr. Strong, with Mr. Paul, conducted excavations around the north end of Lake Yojoa, while Mr. Kidder worked on the Comayagua River. In May and June the entire expedition worked sites on the Chemelicon River, including the site of Naco, first visited by Cortez and the early Spanish Conquistadores.

On the Ulua River excellent stratigraphic series were secured of the prehistoric polychrome pottery horizons. At Playa de los Muertos, on the Ulua, these horizons, corresponding roughly to the close of the Maya Old Empire, were found to overlay a much earlier living level marked by monochrome, polished, and incised pottery.

The work of the expedition approached conclusion in June, and on June 30 preparations for departure began. Throughout its entire work the expedition received cordial cooperation and assistance from

the government of the Republic of Honduras. It was also materially aided by the United Fruit Company, from whose employees it received unlimited hospitality. Without these much appreciated sources of cooperation its scientific results would have been much curtailed.

Dr. Julian H. Steward was appointed as associate anthropologist in the Bureau, effective October 21, 1935. During September 1935, prior to reporting to Washington, Dr. Steward traveled to Pendleton, Oreg., for the purpose of making a selection of 200 negatives of ethnological subjects taken by the late Maj. Lee Morehouse. These were purchased by the Bureau from Mrs. L. L. Cornelison, his daughter. From November 16 to December 10, 1935, Dr. Steward was engaged in conducting a W. P. A. archeological project in the vicinity of Miami, Fla. During this time he supervised the excavation of the large mound at Miami Beach and began work on a smaller mound several miles northwest of the city of Miami. Because of Dr. Strong's departure for Honduras, when Dr. Steward returned to Washington he was delegated to continue the cooperative work between the Bureau of Indian Affairs and the Bureau of American Ethnology previously conducted by Dr. Strong. In connection with these duties Dr. Steward made an extended trip from March 7 to April 15, 1936, in the interest of the Bureau of Indian Affairs. On June 19 he left Washington for the purpose of continuing his field work among the Shoshoni, Bannock, and Gosiute Indians of Utah, Nevada, and Idaho. During the winter and spring Dr. Steward prepared for publication a series of trait lists collected from the Shoshoni Indians of Nevada during the summer of 1935. From other material collected at the same time he completed two articles entitled "Shoshoni Polyandry" and "Panatubiji, a Biography of an Owens Valley Paiute." In addition, Dr. Steward completed for publication in the Smithsonian Annual Report an article entitled "Indian Petroglyphs of the United States."

J. N. B. Hewitt, ethnologist, completed a detailed study of the approximate position and territorial habitat of the northern Iroquoian tribes and of the contiguous Algonquian peoples as they were at the time these groups were first visited by the early explorers. Mr. Hewitt also made a historical study for the purpose of showing the marked influence of the principles and aims of the League of the Five Iroquois Tribes as founded by Deganawida in the early sixteenth century on those of the Constitution of the United States.

Mr. Hewitt had previously recorded from the late Chief J. A. Gibson two Onondaga versions of what is fundamentally a single ritual, namely, the Requickening Address. He made a new translation of these, having first revised both texts so that there should be no material differences in the meaning of the two. He also made a careful revision of the Onondaga texts and laws relating to the posi-

tion and powers and limitations of the Federal Chieftains, and also those governing the Chief Warriors.

He also added to the Bureau's collection of ritual wampum strings by completing two new sets of strings made from loose beads on patterns taken from originals in the Museum of the American Indian, Heye Foundation, and a set which was owned by the late Chief David Skye, of the Canadian Six Nations.

During the year Mr. Hewitt continued to represent the Bureau of American Ethnology on the Advisory Committee on Geographic Names, Department of the Interior.

On June 21, 1936, Mr. Hewitt left Washington on field duty, visiting the Tuscarora Reservation near Lewiston, N. Y., and then the Grand River Grant to the Six Nations in Ontario. On the latter reservation he obtained a short Delaware vocabulary and a fine Mohawk text embodying the so-called Handsome Lake Religion, the preparation of which was about completed by the end of the fiscal year.

SPECIAL RESEARCHES

Miss Frances Densmore, a collaborator of the Bureau of American Ethnology, in continuation of her study of Indian music, submitted a manuscript entitled "Dance Songs of the Seminole Indians", with phonograph records and transcriptions of 25 songs. These songs were recorded in February 1932 at Brighton, Fla., by Billie Stewart, one of the best singers in the Cow Creek group of the tribe. Five songs connected with the tribal ball game were presented, together with songs of the alligator, steal-partner, switch-grass, and buffalo dances. The songs of the ball game were sung to bring success and were accompanied by beating on a water-drum hung by a strap from the player's shoulder. A coconut-shell rattle accompanied the dances. All the songs of each series were recorded. This afforded an opportunity to note the maintaining of a fundamental pitch throughout the series, with a pleasing variation of rhythm in the several melodies.

EDITORIAL WORK AND PUBLICATIONS

The editing of the publications of the Bureau was continued through the year by Stanley Searles, editor. In addition to the current work of the office the comprehensive manuscript index of Bulletins 1–100 has been corrected. All entries have been verified.

An index of Schoolcraft's "Indian Tribes", in six volumes, is nearing completion. More than 30,000 entries have been made and are now being alphabetized.

Bulletin 112, "An Introduction to Pawnee Archeology", by Waldo Rudolph Wedel, and Bulletin 113, "The Troyville Mounds, Catahoula Parish, Louisiana", by Winslow M. Walker, were issued.

Work has been done on other manuscripts in the custody of the editor.

Publications distributed totaled 9,337.

Miss Ella Leary continued in charge as librarian until February 29, 1936, when she was retired on account of ill health. Miss Miriam B. Ketchum was appointed to succeed her, effective April 1, 1936.

The following figures apply to bound books and pamphlets of 100 pages or over. Pamphlets of less than 100 pages are no longer accessioned.

Books received by purchase	18
Books received by exchange	62
Books received by gift	19
Total	99

Numerous pamphlets have been received, as well as the usual periodicals and society transactions, mostly by exchange or gift.

The library contains, as of June 30, 1936:

Total accession record	31, 200
Total withdrawals and losses	661
Net total	30, 539

There are also about 20,000 pamphlets and more than 3,000 volumes of unbound periodicals and society transactions.

It is planned to reclassify the library according to the Library of Congress scheme of classification, and copies of the scheme in the Bureau's field have been furnished by the Library of Congress. All new material is being put in the new classification, and it is hoped that a real start on older material can be made during the coming year. A shelf list has been begun and will be continued along with the reclassification.

A depository set of Library of Congress catalog cards is being established.

A beginning has been made on refiling the catalog and the task will be completed within the next few months.

ILLUSTRATIONS

Following is a summary of work accomplished by E. G. Cassedy, illustrator:

Graphs_____ 29
Line drawings_____ 163
Maps _____ 12
Photos retouched _____ 10
Tracings_____ 18
Plates assembled _____ 29
Lettering jobs _____ 354
Negatives retouched _____ 6
Photos colored_____ 2
                                                            ____
    Total _____ 623

COLLECTIONS

Accession
number

135,291. Archeological material collected by M. W. Stirling from a village site formerly occupied by the Waccamaw Indians near Myrtle Beach, S. C.

138,344. Two earthenware bowls from the Dragoon Mountains, southeastern Arizona.

138,501. The Mrs. Charles D. Walcott collection of 27 pictures of Navaho sand paintings and four paintings of miscellaneous subjects.

139,472. Ten photographs of Australian natives; 20 lithographs of Congo Negro subjects; 33 slides of subjects from Palestine, Tunis, Syria, etc.

MISCELLANEOUS

During the course of the year information was furnished by members of the Bureau staff in reply to numerous inquiries concerning the North American Indians, both past and present, and the Mexican peoples of the prehistoric and early historic periods. Various specimens sent to the Bureau were identified and data on them furnished for their owners.

Personnel.—Dr. J. H. Steward was appointed associate anthropologist October 21, 1935. Miss Edna Butterbrodt, junior stenographer, resigned January 12, 1936. Miss Helen Heitkemper was appointed January 28, 1936, to fill the vacancy.

Respectfully submitted.

M. W. STIRLING, *Chief.*

Dr. C. G. ABBOT,
     Secretary, Smithsonian Institution.

APPENDIX 5

REPORT ON THE INTERNATIONAL EXCHANGE SERVICE

Sir: I have the honor to submit the following report on the activities of the International Exchange Service during the fiscal year ended June 30, 1936:

Congress appropriated for that year $44,262, which is an increase of $3,084 over the amount granted for the Service during 1935. The repayments from departmental and other establishments amounted to $3,563.30, making the total resources available for the exchanges during the year $47,825.30.

The total number of packages handled during 1936 was 596,951, a decrease of 57,180. The weight was 618,789 pounds, an increase of 58,408 pounds.

The material sent and received through the International Exchange Service is placed under three classes—parliamentary documents, departmental documents, and scientific and literary publications. The following table gives the number and weight of packages containing the publications coming under those headings.

	Packages		Weight	
	Sent	Received	Sent	Received
			Pounds	*Pounds*
United States parliamentary documents sent abroad_____	268, 836	_____	109, 717	_____
Publications received in return for parliamentary documents___	_____	12, 401	_____	35, 575
United States departmental documents sent abroad_____	103, 544	_____	112, 124	_____
Publications received in return for departmental documents____	_____	9, 748	_____	32, 678
Scientific and literary publications sent abroad_____	146, 603	_____	217, 275	_____
Scientific and literary publications received from abroad for distribution in the United States_____	_____	55, 819	_____	111, 420
Total_____	518, 983	77, 968	439, 116	179, 673
Grand total_____	596,951		618,789	

During the year 2,475 boxes were shipped abroad, an increase of 288 over the preceding 12 months. Of these boxes, 529 were for the foreign depositories of full sets of United States governmental documents and the remainder (1,946) were for distribution to miscellaneous establishments and individuals.

As has been referred to in previous reports, in addition to the packages forwarded in boxes for distribution by foreign exchange bureaus, many are mailed directly to their destinations—some because

it is more economical to send by mail than by freight; some, like the daily issue of the Congressional Record, because treaty stipulations provide that they shall be so forwarded; and some for the reason that they are for places remote from existing exchange agencies. The total number of packages transmitted by mail during the year was 70,899, an increase of 12,026 over last year.

FOREIGN DEPOSITORIES OF GOVERNMENTAL DOCUMENTS

The number of full sets of governmental publications forwarded abroad is 61 and of partial sets 50, making a total of 111 sets. The depository of the partial set sent to Bengal has been changed from the Department of Education to the Bengal Legislative Council Department, Calcutta. A complete list of the depositories is given below:

DEPOSITORIES OF FULL SETS

ARGENTINA: Ministerio de Relaciones Exteriores, Buenos Aires.
    BUENOS AIRES: Biblioteca de la Universidad Nacional de La Plata, La Plata. (Depository of the Province of Buenos Aires.)
AUSTRALIA: Library of the Commonwealth Parliament, Canberra.
    NEW SOUTH WALES: Public Library of New South Wales, Sydney.
    QUEENSLAND: Parliamentary Library, Brisbane.
    SOUTH AUSTRALIA: Parliamentary Library, Adelaide.
    TASMANIA: Parliamentary Library, Hobart.
    VICTORIA: Public Library of Victoria, Melbourne.
    WESTERN AUSTRALIA: Public Library of Western Australia, Perth.
AUSTRIA: National-Bibliothek, Wien I.
BELGIUM: Bibliothèque Royale, Bruxelles.
BRAZIL: Bibliotheca Nacional, Rio de Janeiro.
CANADA: Library of Parliament, Ottawa.
    MANITOBA: Provincial Library, Winnipeg.
    ONTARIO: Legislative Library, Toronto.
    QUEBEC: Library of the Legislature of the Province of Quebec.
CHILE: Biblioteca del Congreso, Santiago.
CHINA: National Central Library, Nanking.
COLOMBIA: Biblioteca Nacional, Bogotá.
COSTA RICA: Oficina de Depósito y Canje Internacional de Publicaciones, San José.
CUBA: Secretaría de Estado (Asuntos Generales y Canje Internacional), Habana.
CZECHOSLOVAKIA: Bibliothèque de l'Assemblée Nationale, Prague.
DENMARK: Kongelige Bibliotheket, Copenhagen.
EGYPT: Bureau des Publications, Ministère des Finances, Cairo.
ESTONIA: Riigiraamatukogu (State Library), Tallinn.
FRANCE: Bibliothèque Nationale, Paris.
GERMANY: Reichstauschstelle im Reichsministerium des Innern, Berlin C 2.
    BADEN: Universitäts-Bibliothek, Freiburg. (Depository of the State of Baden.)
    BAVARIA: Bayerische Staatsbibliothek, München.
    PRUSSIA: Preussische Staatsbibliothek, Berlin, N. W. 7.
    SAXONY: Sächsische Landesbibliothek, Dresden—N. 6.
    WURTEMBURG: Landesbibliothek, Stuttgart.

GREAT BRITAIN:
  ENGLAND: British Museum, London.
  GLASGOW: City Librarian, Mitchell Library, Glasgow.
  LONDON: London School of Economics and Political Science.   (Depository
    of the London County Council.)
HUNGARY: A Magyar országgyülés könyvtará, Budapest.
INDIA: Imperial Library, Calcutta.
IRISH FREE STATE: National Library of Ireland, Dublin.
ITALY: Ministero dell'Educazione Nazionale, Rome.
JAPAN: Imperial Library of Japan, Tokyo.
LATVIA: Bibliothèque d'État, Riga.
LEAGUE OF NATIONS: Library of the League of Nations, Geneva, Switzerland.
MEXICO: Biblioteca Nacional, Mexico, D. F.
NETHERLANDS: Royal Library, The Hague.
NEW ZEALAND: General Assembly Library, Wellington.
NORTHERN IRELAND: H. M. Stationery Office, Belfast.
NORWAY: Universitets-Bibliothek, Oslo.   (Depository of the Government of
    Norway.)
PERU: Sección de Propaganda y Publicaciones, Ministerio de Relaciones Ex-
    teriores, Lima.
POLAND: Bibliothèque Nationale, Warsaw.
PORTUGAL: Bibliotheca Nacional, Lisbon.
RUMANIA: Academia Română, Bucharest.
SPAIN: Servicio de Cambio Internacional de Publicaciones, Paseo de Recoletos 20,
    Madrid.
SWEDEN: Kungliga Biblioteket, Stockholm.
SWITZERLAND: Bibliothèque Centrale Fédérale, Berne.
TURKEY: Ministère de l'Instruction Publique, Ankara.
UNION OF SOUTH AFRICA: State Library, Pretoria, Transvaal.
UNION OF SOVIET SOCIALIST REPUBLICS: State Central Book Chamber, Moscow 4.
    UKRAINE: All-Ukrainian Association for Cultural Relations with Foreign
      Countries, Kiev.
URUGUAY: Oficina de Canje Internacional de Publicaciones, Montevideo.
VENEZUELA: Biblioteca Nacional, Caracas.
YUGOSLAVIA: Ministère de l'Éducation, Belgrade.

DEPOSITORIES OF PARTIAL SETS

AFGHANISTAN: Ministry of Foreign Affairs, Publications Department, Kabul.
AUSTRIA:
    Vienna: Magistrat der Stadt Wien, Abteilung 51-Statistik.
BOLIVIA: Biblioteca del H. Congreso Nacional, La Paz.
BRAZIL:
    MINAS GERAES: Directoria Geral de Estatistica em Minas, Bello Horizonte.
    RIO DE JANEIRO: Bibliotheca da Assemblea Legislativa do Estado, Nictheroy.
BRITISH GUIANA: Government Secretary's Office, Georgetown, Demerara.
BULGARIA: Ministère des Affaires Étrangères, Sofia.
CANADA:
  ALBERTA: Provincial Library, Edmonton.
    BRITISH COLUMBIA: Provincial Library, Victoria.
    NEW BRUNSWICK: Legislative Library, Fredericton.
    NOVA SCOTIA: Provincial Secretary of Nova Scotia, Halifax.
    PRINCE EDWARD ISLAND: Legislative Library, Charlottetown.
    SASKATCHEWAN: Government Library, Regina.
CEYLON: Chief Secretary's Office (Record Department of the Library), Colombo.

CHINA: National Library, Peiping.
DANZIG: Stadtbibliothek, Danzig.
DOMINICAN REPUBLIC: Biblioteca del Senado, Ciudad Trujillo.
ECUADOR: Biblioteca Nacional, Quito.
FINLAND: Parliamentary Library, Helsingfors.
GERMANY:
    BREMEN: Senatskommission für Reichs- und Auswärtige Angelegenheiten.
    HAMBURG: Staats-und Universitäts-Bibliothek.
    HESSE: Universitäts-Bibliothek, Giessen.
    LÜBECK: President of the Senate.
    THURINGIA: Rothenberg-Bibliothek, Landesuniversität, Jena.
GREECE: Library of Parliament, Athens.
GUATEMALA: Biblioteca Nacional, Guatemala.
HAITI: Secrétaire d'État des Relations Extérieures, Port-au-Prince.
HONDURAS: Biblioteca y Archivo Nacionales, Tegucigalpa.
ICELAND: National Library, Reykjavik.
INDIA:
    ASSAM: General and Judicial Department, Shillong.
    BENGAL: Secretary, Bengal Legislative Council Department, Council House, Calcutta.
    BIHAR AND ORISSA: Revenue Department, Patna.
    BOMBAY: Undersecretary to the Government of Bombay, General Department, Bombay.
    BURMA: Secretary to the Government of Burma, Education Department, Rangoon.
    CENTRAL PROVINCES: General Administration Department, Nagpur.
    MADRAS: Chief Secretary to the Government of Madras, Public Department, Madras.
    PUNJAB: Chief Secretary to the Government of the Punjab, Lahore.
    UNITED PROVINCES OF AGRA AND OUDH: University of Allahabad, Allahabad.
JAMAICA: Colonial Secretary, Kingston.
LIBERIA: Department of State, Monrovia.
LITHUANIA: Ministère des Affaires Étrangères, Kaunas (Kovno).
MALTA: Minister for the Treasury, Valletta.
NEWFOUNDLAND: Department of Home Affairs, St. John's.
NICARAGUA: Superintendente de Archivos Nacionales, Managua.
PANAMA: Secretaría de Relaciones Exteriores, Panama.
PARAGUAY: Secretario de la Presidencia de la República, Asunción.
SALVADOR: Ministerio de Relaciones Exteriores, San Salvador.
SIAM: Department of Foreign Affairs, Bangkok.
STRAITS SETTLEMENTS: Colonial Secretary, Singapore.
VATICAN CITY: Biblioteca Apostolica Vaticana, Vatican City, Rome, Italy.

INTERPARLIAMENTARY EXCHANGE OF THE OFFICIAL JOURNAL

The forwarding of the Congressional Record to the Province of Buenos Aires has been discontinued, and there has been added to the list of recipients of the Record the Biblioteca del Parlament de Catalunya, Barcelona, Spain. The depository in Guatemala has been changed to Biblioteca de la Asamblea Legislativa, Guatemala. The Record sent to Uruguay is now mailed to Diario Oficial, Montevideo.

The Federal Register has been added to the sendings of the Congressional Record. There now are 102 copies of the Record forwarded abroad. A complete list of the depositories is given below.

DEPOSITORIES OF CONGRESSIONAL RECORD

ALBANIA: Ministrija Mibretnore e Punëvetë Jashtme, Tirana.
ARGENTINA:
    Biblioteca del Congreso Nacional, Buenos Aires.
    Cámara de Diputados, Oficina de Información Parlamentaria, Buenos Aires.
AUSTRALIA:
    Library of the Commonwealth Parliament, Canberra.
    NEW SOUTH WALES: Library of Parliament of New South Wales, Sydney.
    QUEENSLAND: Chief Secretary's Office, Brisbane.
    WESTERN AUSTRALIA: Library of Parliament of Western Australia, Perth.
AUSTRIA: Bibliothek des Hauses der Bundesgesetzgebung, Wien, I.
BELGIUM: Bibliothèque de la Chambre des Représentants, Bruxelles.
BOLIVIA: Biblioteca del H. Congreso Nacional, La Paz.
BRAZIL:
    Bibliotheca do Congresso Nacional, Rio de Janeiro.
    AMAZONAS: Archivo, Bibliotheca e Imprensa Publica, Manáos.
    BAHIA: Governador do Estado da Bahia, São Salvador.
    ESPIRITO SANTO: Presidencia do Estado do Espirito Santo, Victoria.
    RIO GRANDE DO SUL: "A Federação", Porto Alegre.
    SÃO PAULO: Diario Official do Estado de São Paulo, São Paulo.
    SERGIPE: Bibliotheca Publica do Estado de Sergipe, Aracajú.
BRITISH HONDURAS: Colonial Secretary, Belize.
CANADA:
    Library of Parliament, Ottawa.
    Clerk of the Senate, Houses of Parliament, Ottawa.
CHINA: National Central Library, Nanking.
CUBA: Biblioteca del Capitolio, Habana.
CZECHOSLOVAKIA: Bibliothèque de l'Assemblée Nationale, Prague.
DANZIG: Stadtbibliothek, Danzig.
DENMARK: Rigsdagens Bureau, Copenhagen.
DOMINICAN REPUBLIC: Biblioteca del Senado, Ciudad Trujillo.
DUTCH EAST INDIES: Volksraad von Nederlandsch-Indië, Batavia, Java.
EGYPT: Bureau des Publications, Ministère des Finances, Cairo.
ESTONIA: Riigiraamatukogu (State Library), Tallinn.
FRANCE:
    Chambre des Députés, Service de l'Information Parlementaire Étrangère, Paris.
    Bibliothèque du Sénat, au Palais du Luxembourg, Paris.
    Bibliothèque, Direction des Accords commerciaux, Ministère du Commerce, Paris.
GERMANY:
    Deutsche Reichstags-Bibliothek, Berlin, N. W. 7.
    Reichsfinanzministerium, Berlin, W. 8.
    ANHALT: Anhaltische Landesbücherei, Dessau.
    BRAUNSCHWEIG: Bibliothek des Braunschweigischen Staatsministeriums, Braunschweig.
    MECKLENBURG: Staatsministerium, Schwerin.
    OLDENBURG: Oldenburgisches Staatsministerium, Oldenburg i. O.
    PRUSSIA: Bibliothek des Preussischen Landtages, Berlin, S. W. 11.
    SCHAUMBURG-LIPPE: Schaumburg-Lippische Landesregierung, Bücheburg.

GIBRALTAR: Gibraltar Garrison Library Committee, Gibraltar.
GREAT BRITAIN: Library of the Foreign Office, London.
GREECE: Library of Parliament, Athens.
GUATEMALA: Biblioteca de la Asamblea Legislativa, Guatemala.
HONDURAS: Biblioteca del Congreso Nacional, Tegucigalpa.
HUNGARY: A Magyar országgyülés könyvtará, Budapest.
INDIA: Legislative Department, Simla.
IRAN: Library of the Iranian Parliament, Téhéran.
IRAQ: Chamber of Deputies, Bagdad, Iraq (Mesopotamia).
IRISH FREE STATE: Dail Eireann, Dublin.
ITALY:
   Biblioteca della Camera dei Deputati, Rome.
   Biblioteca del Senato del Regno, Rome.
   Ufficio degli Studi Legislativi, Senato del Regno, Rome.
LATVIA: Valsts Biblioteka, Riga.
LEAGUE OF NATIONS: Library of the League of Nations, Geneva, Switzerland.
LIBERIA: Department of State, Monrovia.
MEXICO: Secretaría de la Cámara de Diputados, Mexico, D. F.
   AGUASCALIENTES: Gobernador del Estado de Aguascalientes, Aguascalientes.
   CAMPECHE: Gobernador del Estado de Campeche, Campeche.   ·
   CHIAPAS: Gobernador del Estado de Chiapas, Tuxtla Gutierrez.
   CHIHUAHUA: Gobernador del Estado de Chihuahua, Chihuahua.
   COAHUILA: Periódico Oficial del Estado de Coahuila, Palacio de Gobierno, Saltillo.
   COLIMA: Gobernador del Estado de Colima, Colima.
   DURANGO: Gobernador Constitucional del Estado de Durango, Durango.
   GUANAJUATO: Secretaría General de Gobierno del Estado, Guanajuato.
   GUERRERO: Gobernador del Estado de Guerrero, Chilpancingo.
   JALISCO: Biblioteca del Estado, Guadalajara.
   LOWER CALIFORNIA: Gobernador del Distrito Norte, Mexicali, B. C., Mexico.
   MEXICO: Gaceta del Gobierno, Toluca, Mexico.
   MICHOACÁN: Secretaría General de Gobierno del Estado de Michoacán, Morelia.
   MORELOS: Palacio de Gobierno, Cuernavaca.
   NAYARIT: Gobernador de Nayarit, Tepic.
   NUEVO LEON: Biblioteca del Estado, Monterey.
   OAXACA: Periódico Oficial, Palacio de Gobierno, Oaxaca.
   PUEBLA: Secretaría General de Gobierno, Puebla.
   QUERETARO: Secretaría General de Gobierno, Sección de Archivo, Queretaro.
   SAN LUIS POTOSI: Congreso del Estado, San Luis Potosi.
   SINALOA: Gobernador del Estado de Sinaloa, Culiacan.
   SONORA: Gobernador del Estado de Sonora, Hermosillo.
   TABASCO: Secretaría General de Gobierno, Sección 3a, Ramo de Prensa, Villahermosa.
   TAMAULIPAS: Secretaría General de Gobierno, Victoria.
   TLAXCALA: Secretaría de Gobierno del Estado, Tlaxcala.
   VERA CRUZ: Gobernador del Estado de Vera Cruz, Departamento de Gobernación y Justicia, Jalapa.
   YUCATÁN: Gobernador del Estado de Yucatán, Mérida, Yucatán.
NEW ZEALAND: General Assembly Library, Wellington.
NORWAY: Storthingets, Bibliothek, Oslo.
PERU: Cámara de Diputados, Lima.
POLAND: Ministère des Affaires Étrangères, Warsaw.
PORTUGAL: Secretario da Assemblea Nacional, Lisboa.

RUMANIA:
> Bibliothèque de la Chambre des Députés, Bucharest.
> Ministère des Affaires Étrangères, Bucharest.

SPAIN:
> Biblioteca del Congreso Nacional, Madrid.
> Catalunya: Biblioteca del Parlament de Catalunya, Barcelona.

SWITZERLAND:
> Bibliothèque de l'Assemblée Fédérale Suisse, Berne.

SYRIA:
> Ministère des Finances de la République Libanaise, Service du Matériel, Beirut.
> Governor of the State of Alaouites, Lattaquié.

TURKEY: Turkish Grand National Assembly, Ankara.

UNION OF SOUTH AFRICA:
> Library of Parliament, Cape Town, Cape of Good Hope.
> State Library, Pretoria, Transvaal.

URUGUAY: Diario Oficial, Calle Florida 1178, Montevideo.

VENEZUELA: Biblioteca del Congreso, Caracas.

VATICAN CITY: Biblioteca Apostolica Vaticana, Rome, Italy.

FOREIGN EXCHANGE AGENCIES

The exchange agency in Peru, formerly conducted under the direction of the Ministerio de Fomento, is now under the Ministerio de Relaciones Exteriores, Sección de Propaganda y Publicaciones, Lima.

The agency in the Union of South Africa has been removed from Pretoria, Transvaal, to Cape Town, Cape of Good Hope. The Government Printing and Stationery Office in Cape Town now acts as the agency.

LIST OF EXCHANGE AGENCIES

ALGERIA, via France.

ANGOLA, via Portugal.

ARGENTINA: Comisión Protectora de Bibliotecas Populares, Canje Internacional, Calle Callao 1540, Buenos Aires.

AUSTRIA: Internationale Austauschstelle, National-Bibliothek, Wien, I.

AZORES, via Portugal.

BELGIUM: Service Belge des Échanges Internationaux, Bibliothèque Royale de Belgique, Bruxelles.

BOLIVIA: Oficina Nacional de Estadística, La Paz.

BRAZIL: Serviço de Permutações Internacionaes, Bibliotheca Nacional, Rio de Janeiro.

BRITISH GUIANA: Royal Agricultural and Commercial Society, Georgetown.

BRITISH HONDURAS: Colonial Secretary, Belize.

BULGARIA: Institutions Scientifiques de S. M. le Roi de Bulgarie, Sofia.

CANADA: Sent by mail.

CANARY ISLANDS, via Spain.

CHILE: Servicio de Canjes Internacionales, Biblioteca Nacional, Santiago.

CHINA: Bureau of International Exchange, National Central Library, Nanking.

COLOMBIA: Oficina de Canjes Internacionales y Reparto, Biblioteca Nacional, Bogotá.

COSTA RICA: Oficina de Depósito y Canje Internacional de Publicaciones, San José.

CUBA: Sent by mail.

CZECHOSLOVAKIA: Service Tchécoslovaque des Échanges Internationaux, Bibliothèque de l'Assemblée Nationale, Prague 1–79.

DANZIG: Amt für den Internationalen Schriftenaustausch der Freien Stadt Danzig, Stadtbibliothek, Danzig.

DENMARK: Service Danois des Échanges Internationaux, Kongelige Danske Videnskabernes Selskab, Copenhagen V.

DUTCH GUIANA: Surinaamsche Koloniale Bibliotheek, Paramaribo.

ECUADOR: Ministerio de Relaciones Exteriores, Quito.

EGYPT: Government Press, Publications Office, Bulaq, Cairo.

ESTONIA: Riigiraamatukogu (State Library), Tallinn.

FINLAND: Delegation of the Scientific Societies of Finland, Kasärngatan 24, Helsingfors.

FRANCE: Service Français des Échanges Internationaux, 110 Rue de Grenelle, Paris.

GERMANY: Amerika-Institut, Universitätstrasse 8, Berlin, N. W. 7.

GREAT BRITAIN AND IRELAND: Wheldon & Wesley, 2–4 Arthur St., New Oxford St., London, W. C. 2.

GREECE: Bibliothèque Nationale, Athens.

GREENLAND, via Denmark.

GUATEMALA: Instituto Nacional de Varones, Guatemala.

HAITI: Secrétaire d'État des Relations Extérieures, Port-au-Prince.

HONDURAS: Biblioteca Nacional, Tegucigalpa.

HUNGARY: Hungarian Libraries Board, Ferenciektere 5, Budapest, IV.

ICELAND, via Denmark.

INDIA: Superintendent of Government Printing and Stationery, Bombay.

ITALY: R. Ufficio degli Scambi Internazionali, Ministero dell' Educazione Nazionale, Rome.

JAMAICA: Institute of Jamaica, Kingston.

JAPAN: Imperial Library of Japan, Uyeno Park, Tokyo.

JAVA, via Netherlands.

KOREA: Sent by mail.

LATVIA: Service des Échanges Internationaux, Bibliothèque d'État de Lettonie, Riga.

LIBERIA: Bureau of Exchanges, Department of State, Monrovia.

LITHUANIA: Sent by mail.

LOURENÇO MARQUEZ, via Portugal.

LUXEMBOURG, via Belgium.

MADAGASCAR, via France.

MADEIRA, via Portugal.

MEXICO: Sent by mail.

MOZAMBIQUE, via Portugal.

NETHERLANDS: International Exchange Bureau of the Netherlands, Royal Library, The Hague.

NEW SOUTH WALES: Public Library of New South Wales, Sydney.

NEW ZEALAND: General Assembly Library, Wellington.

NICARAGUA: Ministerio de Relaciones Exteriores, Managua.

NORWAY: Service Norvégien des Échanges Internationaux, Bibliothèque de l'Université Royale, Oslo.

PALESTINE: Hebrew University Library, Jerusalem.

PANAMA: Sent by mail.
PARAGUAY: Sección Canje Internacional de Publicaciones del Ministerio de Relaciones Exteriores, Asunción.
PERU: Sección de Propaganda y Publicaciones, Ministerio de Relaciones Exteriores, Lima.
POLAND: Service Polonais des Échanges Internationaux, Bibliothèque Nationale, Warsaw.
PORTUGAL: Secção de Trocas Internacionaes, Bibliotheca Nacional, Lisboa.
QUEENSLAND: Bureau of Exchanges of International Publications, Chief Secretary's Office, Brisbane.
RUMANIA: Bureau des Échanges Internationaux, Institut Météorologique Central, Bucharest.
SALVADOR: Ministerio de Relaciones Exteriores, San Salvador.
SIAM: Department of Foreign Affairs, Bangkok.
SOUTH AUSTRALIA: South Australian Government Exchanges Bureau, Government Printing and Stationery Office, Adelaide.
SPAIN: Servicio de Cambio Internacional de Publicaciones, Paseo de Recoletos 20, bajo derecha, Madrid.
SUMATRA, via Netherlands.
SWEDEN: Kongliga Svenska Vetenskaps Akademien, Stockholm.
SWITZERLAND: Service Suisse des Échanges Internationaux, Bibliothèque Centrale Fédérale, Berne.
SYRIA: American University of Beirut.
TASMANIA: Secretary to the Premier, Hobart.
TRINIDAD: Royal Victoria Istitute of Trinidad and Tobago, Port-of-Spain.
TUNIS, via France.
TURKEY: Robert College, Istanbul.
UNION OF SOUTH AFRICA: Government Printing and Stationery Office, Cape Town, Cape of Good Hope.
UNION OF SOVIET SOCIALIST REPUBLICS: Library of the Academy of Sciences of the U. S. S. R., Exchange Service, Leningrad V. O.
URUGUAY: Oficina de Canje Internacional de Publicaciones, Ministerio de Relaciones Exteriores, Montevideo.
VENEZUELA: Biblioteca Nacional, Caracas.
VICTORIA: Public Library of Victoria, Melbourne.
WESTERN AUSTRALIA: Public Library of Western Australia, Perth.
YUGOSLAVIA: Section des Échanges Internationaux, Ministère des Affaires Étrangères, Belgrade.

Respectfully submitted.

C. W. SHOEMAKER, *Chief Clerk.*

Dr. C. G. ABBOT,
Secretary, Smithsonian Institution.

APPENDIX 6

REPORT ON THE NATIONAL ZOOLOGICAL PARK

Sir: I have the honor to submit the following report on the operations of the National Zoological Park for the fiscal year ended June 30, 1936:

The regular appropriation made by Congress for the maintenance of the Park was $215,000. The total expenditures for the year from this appropriation were about $214,200.

IMPROVEMENTS

The fiscal year 1936 marked the beginning of more substantial improvements than had ever before been made in any one year or a considerable period of years in the Zoo. Under a grant from the Public Works Administration of $680,000, supplemented later by $191,575, contracts were let and work begun on five projects. These include machine and carpenter shops and a garage; the installation of three 250-horsepower down draft boilers, which will serve to heat all of the exhibition buildings with the exception of the bird house, which was considered as being too remote from the others to warrant a conduit being built to it; a brick exhibition building approximately 185 by 115 feet for small mammals and great apes; a stone exhibition building 227 by 90 feet to house large animals, such as elephant, rhinoceros, and hippopotamus; and a new wing to the bird house.

The machine shop and central heating plant will be completed in time to supply heat to the buildings in the fall. The other buildings should be finished by January 1, 1937.

The completion of these projects will give the Zoo four large, modern buildings containing numbers of new features for the exhibition of animals and is the greatest improvement in the history of the Zoo.

With the use of labor assigned to us through the District Works Progress Administration and some material from the same source, together with materials purchased from our regular appropriation, 5,083 linear feet of concrete road and walk curbing were constructed and 4,112 square yards of roads and walks were given bitulithic surfacings. Also 14,038 square yards of road were tarred, graveled, and rolled. The worst of the holes in the road between the mechanical shops and the crossroads at the Harvard Street entrance were repaired preparatory to a tar-gravel treatment when the construction

work at the shops is finished. Terra cotta sewer, 1,700 linear feet of 12-inch diameter, was laid from the District sewer along the creek to the vicinity of the great flight cage in the ravine. This was a step in the line of diverting all sanitary sewerage from the creek into the District's sanitary sewers. Repairs were also made to the storm water sewers in the same ravine, and 2,000 feet of various sized water lines were laid.

The improvement of the grounds by planting grass, shrubs, and trees, removal of objectionable or surplus vegetation, grading, and related grounds work has been carried on with very satisfactory results. Material progress has been made in the removal of poison ivy.

A small amount of miscellaneous repairs to buildings and fences has been carried out with funds from our regular appropriation and unskilled labor assigned to us under W. P. A. When certain W. P. A. clerical employees assigned to the Zoo were not urgently needed on routine work directly connected with the W. P. A., they rendered substantial assistance in repairing a considerable number of valuable pamphlets relating to zoology and in arranging them in the Zoo library. Just at the close of the year a bookbinder assigned to the Institution by the W. P. A. was detailed to this branch of the Smithsonian library. This arrangement is most promising for the binding and repairing of many valuable publications in our excellent vertebrate zoology library which otherwise would rapidly deteriorate.

VISITORS FOR THE YEAR

July	208, 300	February	30, 400
August	248, 050	March	173, 400
September	269, 200	April	241, 300
October	187, 400	May	361, 500
November	104, 950	June	303, 500
December	56, 450		
January	51, 400	Total	2, 235, 850

The attendance of organizations, mainly classes of students, of which there is definite record was 33,321 from 579 different schools in 20 States and the District of Columbia, as follows:

State	Number of persons	Number of parties	State	Number of persons	Number of parties
Connecticut	83	2	Ohio	896	20
Delaware	382	8	Oregon	35	1
District of Columbia	7, 146	132	Pennsylvania	8, 232	143
Georgia	92	3	South Carolina	112	4
Maine	70	2	South Dakota	32	1
Maryland	5, 739	82	Tennessee	24	1
Massachusetts	373	9	Virginia	5, 106	86
Michigan	220	5	West Virginia	595	7
New Hampshire	34	1	Conventions—Members of		
New Jersey	2, 132	30	various States	160	2
New Mexico	19	1			
New York	954	16	Total	33, 321	579
North Carolina	885	23			

About 3 o'clock every afternoon, except Sunday, a census is made of the cars parked on the Zoo grounds. During the year 22,997 were so listed, representing every State in the Union, Hawaii, Canada, Canal Zone, Alaska, and Cuba. Since the total number is merely a record of those actually parked at one time, it is not of value as indicating a total attendance but is of importance as showing the percentage attendance by States, Territories, and countries. The District of Columbia comprised slightly over 52 percent; Maryland, 19 percent; Virginia, 11 percent; and the remaining cars were from other States, Territories, and countries. During years in which counts have been made on Sunday as well as during the week it has been found that the percentage of cars from the District of Columbia, Maryland, and Virginia is less, and the percentage of the more distant States is correspondingly increased. This is brought about by tourists coming to the Zoo on Sundays when other points of interest are closed to them.

ACCESSIONS

Gifts.—The collection was enriched by a number of important gifts. A Hood Island tortoise was received from Rear Admiral C. S. Freeman, United States Navy. From Mrs. A. N. Pack, Espanola, N. Mex., a splendid pair of pumas were received. Elisha Hansen, Washington, D. C., presented a black-striped wallaby. A number of rare frogs of the genera *Dendrobates* and *Atelopus* were received from Dr. E. R. Dunn, Haverford, Pa. Miss Gloria Hollister, of the New York Zoological Society, presented three Trinidad vampire bats. R. E. Stadelmann, traveling in Central and South America, continued his generosity and interest in the Park with several shipments of reptiles.

DONORS AND THEIR GIFTS

Mrs. Chas. L. Anderson, Washington, D. C., nighthawk.
A. G. Aquayo and P. J. Bermidez, Cuba, 6 diving anolis lizards.
M. C. Arner, Trinidad, British West Indies, giant centipede.
Miss Helen Ault, Washington, D. C., white-throated capuchin.
Miss Ellen Babcock, Alexandria, Va., 2 Pekin ducks.
Vernon Bailey, Washington, D. C., hog-nosed snake.
George W. Baker, Washington, D. C., hog-nosed snake.
D. S. Basin, Washington, D. C., raccoon.
Chas. A. Bechtold, Laurel, Md., blacksnake.
J. S. Beck, Washington, D. C., flying squirrel.
Mrs. E. M. Betts, Hampton, Va., alligator.
Marion Bird, La Crosse, Wis., spotted salamander.
Mr. and Mrs. J. S. C. Boswell, Alexandria, Va., corn snake, chicken snake.
E. S. Bowles, Washington, D. C., copperhead snake, coleonyx lizard.
Albert Bricker, Washington, D. C., weasel.
Ralph Britt, Chevy Chase, Md., barn owl.

J. L. Brooks, Washington, D. C., alligator.
G. A. and E. F. Brown, Washington, D. C., marine turtle.
Maurice M. Brown, Jr., Colonial Beach, Va., 2 little blue herons.
S. K. Brown, Eustis, Fla., coral snake, pine snake, corn snake.
F. R. Browne, Ashburn, Ga., hog-nosed snake, water snake, garter snake.
W. E. Buck, Camden, N. J., gaboon viper.
Eddie Buell, Washington, D. C., bald eagle.
Miss Brooksie Burnette, Silver Spring, Md., snapping turtle.
John F. Burrows, Washington, D. C., weasel.
Dr. Chas. E. Burt, Winfield, Kans., 11 gray skinks.
W. H. Calfee, Washington, D. C., common duck.
M. Wayne Carney, Washington, D. C., 2 skunks.
Wm. Carr, Bear Mountain Park, N. Y., watersnake, mole snake, garter snake.
E. W. Clark, Detroit, Mich., 3 massasaugas.
Mrs. L. P. Coakley, Washington, D. C., alligator.
Mrs. W. G. Cooper, Washington, D. C., Pekin duck.
A. C. Cornett, Smithfield, Va., hawk.
Jess S. Cottrell, Washington, D. C., alligator.
J. P. Crocker, Washington, D. C., great horned owl.
Mrs. Crowell, Washington, D. C., canary.
C. L. Cummell, Washington, D. C., barred owl.
L. Danaher, Meriden, Conn., hog-nosed snake.
Mrs. W. C. Daudt, Washington, D. C., Cumberland terrapin.
J. H. Davis, Hyattsville, Md., opossum.
Chas. F. Denley, Glenmont, Md., Lady Amherst's pheasant, Elliot's pheasant.
J. Dickson, Eheart, Va., banded rattlesnake.
Miss Helen Dougherty, Atlantic City, N. J., yellow-fronted parrot.
H. W. Draper, Washington, D. C., alligator.
Dr. E. R. Dunn, Haverford, Pa., 8 red dendrobates, 10 yellow atelopus.
Mr. Dureen, Washington, D. C., alligator.
Chas E. Eaton, Washington, D. C., 3 common chameleons.
David Elsasser, Johnstown, Pa., weeping capuchin.
Dr. W. O. Emery, Washington, D. C., 4 fire-bellied toads.
M. L. Ernst, Washington, D. C., rough-scaled green snake.
H. P. Erwin, Washington, D. C., Cooper's hawk.
Bobbie Farrington, Washington, D. C., ring-necked pheasant.
John C. Finch, Washington, D. C., rhesus monkey.
Florida Reptile Institute, Silver Springs, Fla., 6 scorpions, fox squirrel, blue land
    crab.
A. Foehl, Jr., Philadelphia, Pa., banded basilisk, 5 frogs.
Rear Admiral C. S. Freeman, U. S. N., Hood Island tortoise.
John Freeman, Washington, D. C., white-throated capuchin.
M. P. Freeman, Washington, D. C., raccoon.
Dick George, Washington, D. C., Pekin duck.
C. K. Gibson, Washington, D. C., 2 Pekin ducks.
Truxton Goodrell, Washington, D. C., pilot snake.
W. S. Green, Greenwood, Va., weeping capuchin.
Mrs. W. E. Gregg, Chevy Chase, Md., screech owl.
John F. Hamaker, Washington, D. C., crow.
J. E. Hanell, Washington, D. C., woodchuck.
Elisha Hansen, Washington, D. C., black-striped wallaby.
Geo. Hartnell, Cheltenham, Md., Florida gallinule.
Frank Harvey, Washington, D. C., grass paroquet, 2 canaries.

Ed. Harwell, Wetumpha, Ala., banded rattlesnake.
Harry B. Hawes, Washington, D. C., 2 southern mynahs.
Jas. F. Herbert, Washington, D. C., gray fox.
H. F. Herman, Washington, D. C., razor-billed curassow.
Christian Heurich, Washington, D. C., snapping turtle, blacksnake.
Mrs. Samuel B. Hill, Washington, D. C., California valley quail.
Miss Gloria Hollister, New York City, 3 Trinidad vampire bats.
Maj. J. M. Huddleston, U. S. A., rhesus monkey.
E. C. Hughes, Washington, D. C., copperhead snake.
Maj. E. E. Hume, U. S. A., pigeon.
David Humphrey, Cabin John, Md., copperhead snake.
Carl Imlay, Chevy Chase, D. C., bald eagle, red-shouldered hawk.
J. R. Johnson, Washington, D. C., 2 opossums.
Wm. Johnson, Silver Spring, Md., American coot.
Jos. W. Jones, Bristol, Tenn., horned lizard.
Raymond Kehr, Washington, D. C., yellow-shouldered parrot.
Miss Estelle King, Washington, D. C., red, blue, and yellow macaw.
W. T. King, Washington, D. C., copperhead snake.
Frank Kirby, Washington, D. C., white-throated capuchin.
F. Heber Knight, Washington, D. C., 2 copperhead snakes, screech owl, hog-nosed
    snake.
Miss Selma Krager, Washington, D. C., garter snake.
Mrs. J. A. Kramer, Washington, D. C., red-fronted parrot.
J. C. Lamon, Pickwick Dam, Tenn., hog-nosed snake.
Lester Leigh, Arcadia, Fla., glass snake, horn snake.
Mrs. M. E. Leishear, Washington, D. C., garter snake.
Mrs. Laura E. Lemon, Washington, D. C., domestic pigeon.
Jas. L. Leuenberger, Washington, D. C., goose.
Mrs. A. M. Lockamy, Washington, D. C., alligator.
Daniel C. Long, Washington, D. C., sidewinder rattlesnake.
Dr. J. A. Lyon, Rockville, Md., blue tanager.
J. S. Mansay, Washington, D. C., alligator.
R. W. Martin, LaGrange, Ga., glass snake.
Miss McAlister, Washington, D. C., red fox.
John T. McBurney, Chevy Chase, D. C., copperhead snake, blacksnake, fox
    snake.
Lt. Comm. W. E. McCain, Washington, D. C., yellow-naped parrot.
Chester McCall, Washington, D. C., rough-scaled green snake.
John R. McGrew, Bethesda, Md., blacksnake.
Mrs. A. B. McKean, Washington, D. C., 2 canaries.
F. McLemore, Lorman, Miss., coachwhip snake.
Mrs. Betty McShan, Silver Hill, Md., horned lizard.
Marquis Metts, Mt. Rainier, Md., red-tailed hawk.
A. L. Nelson and F. M. Uhler, Biological Survey, corn snake.
Ex-Postmaster Gen. New, Washington, D. C., barred owl.
New York Zoological Park, New York City, 6 gaboon vipers, 5 puff adders.
Mrs. A. N. Pack, Espanola, N. Mex., 2 pumas.
Mrs. H. A. Page, Jr., Aberdeen, N. C., pigmy rattlesnake.
Mrs. N. D. Parker, Woodside, Md., 4 Pekin ducks, 7 white mice.
Mrs. Pawlowski, Washington, D. C., 3 canaries.
S. M. Peel, Washington, D. C., wood tortoise.
G. E. Pelton, Alexandria, Va., cow bird.
Mr. Perkins, Washington, D. C., chain or king snake.

J. P. Phillips, Washington, D. C., loon.
Gregory Pigg, Washington, D. C., opossum.
Bryan Pitt, Washington, D. C., grass paroquet.
G. F. Pollock, Washington, D. C., raven, 4 banded rattlesnakes.
Mrs. G. F. Pollock, Washington, D. C., blacksnake.
Mrs. A. E. Pyles, Friendship Heights, Md., raccoon.
David Rawlings, Chevy Chase, D. C., skunk.
Mrs. A. R. Rea, Washington, D. C., alligator.
Henry Renfrew, Washington, D. C., screech owl.
Dr. F. H. H. Roberts, Jr., Bureau of American Ethnology, 3 western rattle-
    snakes.
J. L. Robertson, U. S. Public Health Service, Washington, D. C., black widow
    spider.
Miss Mary Rogers, Washington, D. C., marine turtle.
Miss Eleanor Roosevelt, Washington, D. C., 9 alligators.
June Rosenthal, Washington, D. C., alligator.
Rotary Eagle Scout Troop No. 3, Reno, Nev., 5 Agassiz's tortoises.
Louis Ruhe, Inc., New York City, Old World wildcat, 2 blue honey-creepers.
Henry C. Sacra, Washington, D. C., red fox.
Andrew Santorios, Washington, D. C., 2 Greek partridges.
Mrs. J. H. Saum, Washington, D. C., canary.
Mrs. James W. Saunders, Washington, D. C., ring-necked dove.
Mrs. S. E. Schoof, Washington, D. C., woodchuck.
Miss Elizabeth Shorey, Washington, D. C., muscovy duck.
R. Shostick, Washington, D. C., salamander.
Dr. J. F. Simpson, Washington, D. C., alligator.
Mrs. H. R. Smith, Washington, D. C., woodchuck.
Norman Smith, Upper Marlboro, Md., great horned owl.
Mrs. Wesley Smith, Washington, D. C., black crowned night heron.
Spanish Legation, Washington, D. C., alligator.
H. V. Stabler, Washington, D. C., king snake, sparrow hawk.
R. E. Stadelmann, Tela, Honduras, 2 South American rat snakes, 2 geckos,
    green tree snake, tree boa, rainbow boa.
Cecil Strickland, Clendenin, W. Va., golden eagle.
Mrs. L. M. Sullivan, Washington, D. C., 4 Mexican grassquits.
John G. Taylor, Richmond, Va., white woodchuck.
Richard Taylor, Bethesda, Md., 3 fence lizards, 2 six-lined lizards.
Taxidermist Shop Staff, National Museum, Washington, D. C., 20 spring peepers.
Mrs. John Terrill, Lock Haven, Pa., double yellow-head parrot.
J. R. Thomas, Baltimore, Md., Javan macaque.
Mrs. W. D. Thomas, Washington, D. C., coyote.
Miss Florence Thwaite, Washington, D. C., praying mantis.
Mrs. V. H. Todd, Washington, D. C., opossum.
Toledo Zoological Park, Toledo, Ohio, ball python.
Mr. and Mrs. Jos. Truitt, Washington, D. C., 2 ferrets.
A. B. Turner, Washington, D. C., sparrowhawk.
Dr. Titus Ulke, Washington, D. C., red-tailed hawk, red-shouldered hawk.
U. S. Biological Survey, through Mr. Kelso, Washington, D. C., Cooper's hawk;
    through Jos. Keyes, Sacramento, Calif., 5 yellow-billed magpies; through
    C. C. Whitaker, Washington, D. C., bay lynx.
U. S. National Park Service, through E. A. Borrell, Grand Canyon, Ariz., Say's
    bull snake, 3 Holbrook's or earless lizards, 2 whiptail lizards, blue-bellied
    lizard.
Maj. Geo. L. Usher, U. S. A., alligator.

Miss Edna L. Vogel, Washington, D. C., alligator.
Clifton A. Wagner, Chevy Chase, Md., red salamander.
Robert Wallace, Washington, D. C., osprey.
Walter Reed Hospital, through Major Reynolds, Washington, D. C., 3 rhesus monkeys.
Mrs. L. T. Weir, Washington, D. C., alligator.
John Weismuller, Washington, D. C., southern skunk.
A. J. Wernig, Washington, D. C., opossum.
Dr. A. Wetmore, National Museum, Washington, D. C., flicker.
Chester Wetzel, Washington, D. C., 2 sparrow hawks.
Master Tom White, Washington, D. C., milk snake.
B. O. Wilbanks, Washington, D. C., copperhead snake.
O. L. Wilkins, West Augusta, Va., 2 banded rattlesnakes.
W. D. Wills, Silver Spring, Md., praying mantis.
B. F. Wood, Washington, D. C., milk snake.
Mrs. M. E. Woodward, Washington, D. C., goose.
G. E. Worthington, Washington, D. C., alligator.
Donor unknown, red-breasted or Brazilian cardinal.

Births.—There were 54 mammals born and 48 birds hatched in the Park during the year. These include the following:

MAMMALS

Scientific name	Common name	Number
Ammotragus lervia	Aoudad	4
Axis axis	Axis deer	2
Bison bison	American bison	4
Capra sibirica	Siberian ibex	2
Cervus canadensis	American elk or wapiti	1
Cervus duvaucelii	Barasingha deer	1
Cervus elaphus	Red deer	5
Dama dama	Fallow deer	7
Dolichotis patagonica	Patagonian cavy	1
Equus przewalskii	Mongolian wild horse	1
Equus quagga chapmani	Chapman's zebra	1
Felis onca	Jaguar	3
Lama glama	Llama	2
Marmota monax	Woodchuck	4
Odocoileus virginianus	Virginia deer	2
Oryx beisa annectens	Ibean beisa oryx	1
Sika nippon	Japanese deer	4
Taurotragus oryx	Eland	1
Thalarctos maritimus × *Ursus gyas*	Polar and Alaska brown bear hybrid	4
Ursus arctos	European brown bear	1
Ursus gyas	Alaska Peninsula bear	2
Zalophus californianus	California sea-lion	1

BIRDS

Ardea herodias × *A. occidentalis*	Hybrid heron	3
Larus delawarensis	Ring-billed gull	1
Larus novaehollandiae	Silver gull	13
Nycticorax nycticorax naevius	Black-crowned night heron	26
Pavo cristatus	Peafowl	4
Phalacrocorax auritus floridanus	Florida cormorant	1

Exchanges.—Notable additions obtained through the medium of exchange were 2 fennecs, 7 Jackson's bustards, an African black rail, 10 soft-shelled tortoises, 4 leopard tortoises, 2 puff adders and various small birds from Christoph Schulz, Arusha, East Africa. A black leopard was obtained from Ellis Joseph, New York City. From the Staten Island Zoo, through the Director, Carol Stryker, a shipment of especially rare specimens was received, including 4 mountain pit vipers, 6 sea snakes, 2 gliding snakes, 2 mangrove snakes, 3 Malay spitting cobras, and 6 prairie rattlesnakes.

Purchases.—Important purchases during the year were a pair of solenodons, a Grevy's zebra, and a trio of gayals, the latter the first ever exhibited at the Park.

REMOVALS

Deaths.—Important losses by death during the year include two jackass penguins, three pumas, a Chapman's zebra, a California sealion, and a lion.

During the year 406 specimens that died were sent to the National Museum.

ANIMALS IN COLLECTION THAT HAD NOT PREVIOUSLY BEEN EXHIBITED

MAMMALS

Scientific name	*Common name*
Bos frontalis	Gayal.
Felis sylvestris	Old World wildcat.
Desmodus rotundus murinus	Vampire bat.

BIRDS

Dissemurus paradiseus	Giant racquet-tailed drongo.
Hypomorphnus urubitinga	Brazilian eagle.

REPTILES

Deiroptyx vermiculatus	Diving anolis lizard.
Laticauda colubrina	Sea snake.
Naja flava	Golden cobra.
Sepedon haemachates	Rhingal or spitting cobra.
Trimeresurus monticola	Mountain pit viper.

Statement of the collection

Class	Presented	Born	Received in exchange	Purchased	On deposit	Total
Mammals	46	54	5	45	14	164
Birds	75	48	26	119	3	271
Reptiles	141		44	68	4	257
Amphibians	40			20		60
Fishes	10			10		20
Arachnids	9					9
Crustaceans	2					2
Insects	3					3
Total	326	102	75	262	21	786

Summary

Animals on hand July 1, 1935_____ 2,170
Accessions during the year_____ 786

Total animals in collection during year_____ 2,956
Removal from collection by death, exchange, and return of animals on
deposit_____ 765

In collection June 30, 1936_____ 2,191

Status of collection

Class	Species	Individuals	Class	Species	Individuals
Mammals	173	529	Insects	2	21
Birds	310	900	Mollusks	1	2
Reptiles	128	366	Crustaceans	1	2
Amphibians	29	184			
Fishes	28	184	Total	675	2,191
Arachnids	3	3			

ANIMALS IN THE NATIONAL ZOOLOGICAL PARK, JUNE 30, 1936

MAMMALS

Marsupialia:

*Didelphis virginiana*_____ Opossum_____ 6

Carnivora:

*Canis latrans*_____ { Coyote_____ 8
{ Albino coyote_____ 1
Canis latrans × *domesticus*_____ Coyote × dog hybrid_____ 2
*Canis lycaon*_____ Timber wolf_____ 2
*Canis nubilus*_____ Plains wolf_____ 8
Canis nubilus × *domesticus*_____ Wolf × dog hybrid_____ 1
*Chrysocyon jubata*_____ Maned wolf_____ 1
*Civettictis civetta*_____ Civet_____ 1
*Crocuta crocuta germinans*_____ East African spotted hyena_____ 1
*Euarctos americanus*_____ American black bear_____ 6
*Euarctos emmonsii*_____ Glacier bear_____ 2
*Felis cattus*_____ Siamese cat_____ 2
*Felis concolor azteca*_____ Mexican puma_____ 3
*Felis concolor oregonensis*_____ Puma_____ 2
*Felis leo*_____ Lion_____ 6
*Felis onca*_____ { Jaguar_____ 4
{ Black jaguar_____ 2
*Felis pardus*_____ { Leopard_____ 2
{ Black leopard_____ 1
*Felis serval*_____ Serval_____ 1
*Felis sylvestris*_____ Old World wildcat_____ 1
*Felis temmincki*_____ Golden cat_____ 1
*Felis tigris longipilis*_____ Siberian tiger_____ 2
*Felis tigris sondaicus*_____ Sumatran tiger_____ 2
*Fennecus zerda*_____ Fennec_____ 2
*Galictis barbara barbara*_____ White tayra_____ 2
*Genetta dongalana neumanni*_____ Neumann's genet_____ 1
*Helarctos malayanus*_____ Malay or sun bear_____ 1

Carnivora—Continued.

Herpestes birmanicus	Burmese mongoose	1
Hyacna brunnea	Brown hyena	2
Lutra canadensis vaga	Florida otter	2
Lycaon pictus	Cape hunting dog	1
Lynx baileyi	Bailey's lynx	1
Lynx caracal	Caracal	1
Lynx rufus	Bay lynx	5
Mellivora capensis	Ratel	1
Mephitis nigra	Skunk	4
Mustela eversmanni	Ferret	5
Nasua narica	Gray coatimundi	3
Nasua nelsoni	Nelson's coatimundi	1
Nyctereutes procyonoides	Raccoon dog	1
Otocyon megalotis	Long-eared fox	1
Potos flavus	Kinkajou	2
Procyon cancrivorus	Crab-eating raccoon	1
Procyon lotor	Albino raccoon	4
	Raccoon	17
Spilogale ambarvalis	Southern skunk	1
Thalarctos maritimus	Polar bear	2
Thalarctos maritimus × Ursus gyas	Polar × Alaska brown bear hybrid	3
Urocyon cinereoargenteus	Gray fox	5
Ursus arctos	European brown bear	4
Ursus gyas	Alaska peninsula brown bear	4
Ursus kidderi	Kidder's bear	2
Ursus middendorffi	Kodiak bear	3
Ursus sitkensis	Sitka brown bear	3
Ursus thibetanus	Himalayan bear	1
Viverra megaspila	Indian palm civet	3
Vulpes fulva	Red fox	8

Pinnipedia:

Eumetopias jubatus	Steller's sea lion	1
Phoca richardii	Pacific harbor seal	3
Zalophus californianus	California sea lion	2

Primates:

Cebus apella	Brown capuchin	1
Cebus capucinus	White-throated capuchin	5
Cebus fatuellus	Weeping capuchin	4
Cebus sp	Gray capuchin	2
Cercocebus fuliginosus	Sooty mangabey	4
Cercopithecus albigularis	Sykes's guenon	2
Cercopithecus brazzae	DeBrazza's guenon	1
Cercopithecus callitrichus	Green guenon	3
Cercopithecus diana	Diana monkey	1
Cercopithecus griseoviridis	Grivet monkey	2
Cercopithecus petaurista	Lesser white-nosed guenon	2
Cercopithecus roloway	Roloway monkey	1
Colobus caudatus	White-tailed guereza	1
Colobus polycomus	White-tailed colobus	1
Lagothrix lagotricha	Woolly monkey	1
Lemur varius	Ruffed lemur	1
Leontocebus geoffroyi	Marmoset	2

Primates—Continued.

Macaca fuscata	Japanese macaque	2
Macaca mordax	Javan macaque	2
Macaca mulatta	Rhesus monkey	12
Macaca nemestrina	Pig-tailed monkey	1
Macaca silenus	Wanderoo monkey	2
Macaca sinica	Bonnet monkey	1
Macaca sp	Macaque monkey	1
Magus maurus	Moor monkey	1
Mandrillus leucophaeus	Drill	1
Mandrillus sphinx	Mandrill	3
Pan calvescens	Chimpanzee	1
Pan satyrus	Chimpanzee	1
Papio anubis	Anubis baboon	1
Papio cynocephalus	Golden baboon	3
Papio hamadryas	Hamadryas baboon	1
Papio porcarius	Chacma	2
Pongo abelii	Sumatran orangutan	1
Symphalangus syndactylus	Siamang gibbon	1
Theropithecus gelada	Gelada baboon	1

Rodentia:

Acanthion brachyurum	Malay porcupine	2
Capromys pilorides	Hutia	6
Castor canadensis	Beaver	2
Cavia porcellus	Domestic guinea pig	1
Citellus mollis	Utah ground squirrel	1
Cuniculus paca virgatus	Central American paca	2
Cynomys ludovicianus	Prairie dog	1
Dasyprocta rubrata	Trinidad agouti	2
Dolichotis megallanica	Patagonian cavy	1
Dolichotis salinicola	Dwarf cavy	2
Glaucomys volans	Flying squirrel	2
Hystrix galeata	East African porcupine	8
Marmota monax	Woodchuck or groundhog	4
	Albino woodchuck or groundhog	1
Myocastor coypu	Coypu	4
Myoprocta sp.	Tailed agouti	1
Sciurus finlaysoni	Lesser white squirrel	3
Sciurus hoffmani sub. sp	Hoffman's squirrel	3
Sciurus niger	Fox squirrel	2
Sciurus sp	Squirrel	1

Lagomorpha:

Oryctolagus cuniculus	Domestic rabbit	2
	Angora rabbit	1

Artiodactyla:

Æpyceros melampus suara	East African impalla	1
Ammotragus lervia	Aoudad	9
Anoa depressicornis	Anoa	1
Antilope cervicapra	Black buck or Indian antelope	1
Axis axis	Axis deer	6
Babirussa alfurus	Babirussa	2
Bison bison	American bison	21
Bos frontalis	Gayal	3
Bos indicus	Zebu	3

Artiodactyla—Continued.

Boselaphus tragocamelus	Nilgai	2
Bubalus bubalis	Indian buffalo	1
Camelus bactrianus	Bactrian camel	1
Camelus dromedarius	Arabian or single-humped camel	3
Capra sibirica	Siberian ibex	4
Cervus canadensis	American elk or wapiti	2
Cervus duvaucelii	Barasingha	4
Cervus elaphus	European red deer	17
Cervus xanthopygus	Bedford deer	2
Choeropsis liberiensis	Pigmy hippopotamus	2
Connochaetes gnu	White-tailed gnu	2
Connochaetes taurinus	Brindled gnu	1
Connochaetes taurinus albojubatus	White-bearded gnu	2
Dama dama	{ Fallow deer	13
	{ White fallow deer	18
Hemitragus jemlahicus	Tahr	4
Hippopotamus amphibius	Hippopotamus	1
Hyelaphus porcinus	Hog deer	2
Lama glama	Llama	7
Lama huanacus	Guanaco	2
Muntiacus sinensis	Barking or rib-faced deer	1
Odocoileus costaricensis	Costa Rican deer	2
Odocoileus virginianus	Virginia deer	6
Onotragus lechee	Lechee antelope	1
Oryx beisa annectens	Ibean beisa oryx	2
Ovis europaeus	Mouflon	5
Pecari angulatus	Collared peccary	3
Phacochoerus aethiopicus massaicus	East African wart hog	3
Poephagus grunniens	Yak	4
Rucervus eldii	Burmese deer	1
Rusa moluccensis	Molucca deer	2
Saiga tatarica	Saiga antelope	2
Sika nippon	Japanese deer	22
Sus scrofa	European wild boar	2
Taurotragus oryx	Eland	2
Tayassu pecari	White-lipped peccary	2

Perissodactyla:

Diceros bicornis	Black rhinoceros	1
Equus grevyi	Grevy's zebra	1
Equus grevyi-asinus	Zebra-ass hybrid	1
Equus grevyi-caballus	Zebra-horse hybrid	1
Equus onager	Asiatic wild ass or kiang	2
Equus przewalskii	Mongolian wild horse	2
Equus quagga chapmani	Chapman's zebra	8
Equus zebra	Mountain zebra	2
Tapirella bairdii	Baird's tapir	1
Tapirus terrestris	Brazilian tapir	1

Proboscidea:

Elephas indicus	Indian elephant	1
Elephas sumatranus	Sumatra elephant	1
Loxodonta africana oxyotis	African elephant	1

Edentata:

Choloepus didactylus	Two-toed sloth	5

BIRDS

Ratitae:
Casuarius unipendiculatus	Single-wattled cassowary	1
Dromiceius novaehollandiac	Common emu	2
Rhea americana	Common rhea or nandu	1
Struthio camelus	Ostrich	2

Pelecaniformes:
Anhinga anhinga	Anhinga	2
Nannopterum harrisi	Flightless cormorant	2
Pelecanus californicus	California brown pelican	2
Pelecanus conspicillatus	Australian pelican	1
Pelecanus erythrarhynchos	American white pelican	8
Pelecanus erythrorhynchos × *P. occidentalis*	Hybrid pelican	1
Pelecanus occidentalis	Brown pelican	4
Pelecanus onacrotalus	European pelican	3
Pelecanus roseus	Rose-colored pelican	2
Phalacrocorax auritus albociliatus	Farallone cormorant	2
Phalacrocorax auritus floridanus	Florida cormorant	3
Sulu granti	Blue-footed booby	1

Ciconiiformes:
Ajaja ajaja	Roseate spoonbill	1
Ardea herodias	Great blue heron	1
Ardea herodias × *A. occidentalis*	Heron hybrid	2
Ardea occidentalis	Great white heron	2
Balaeniceps rex	Shoe-bill heron	1
Cochlearius cochlearius	Boatbill heron	3
Dissura episcopus	Woolly-necked stork	1
Ephippiorhynchus senegalensis	Saddle-billed stork	1
Guara alba	White ibis	5
Guara alba × *G. rubra*	Hybrid scarlet—white ibis	1
Guara rubra	Scarlet ibis	2
Herodias egretta	American egret	1
Leptoptilus crumeniferus	Maribou	1
Leptoptilus dubius	Indian adjutant	1
Leptoptilus javanicus	Lesser adjutant	2
Mycteria americana	Wood ibis	1
Nycticorax nycticorax naevius	Black-crowned night heron	50
Scopus umbretta	Hammerhead	1
Threskiornis aethiopicus	Sacred ibis	2
Threskiornis melanocephalus	Black-headed ibis	2

Anseriformes:
Aix sponsa	Wood duck	6
Alopochen aegyptiacus	Egyptian goose	2
Anas domestica	Peking duck	4
Anas platyrhynchos	Mallard	31
	Call duck (white)	2
Anas rubripes	Black or dusky mallard	2
Anas undulata	African yellow-billed duck	2
Anser albifrons	American white-fronted goose	3
Anser brachyrhynchus	Pink-footed goose	1
Anser fabalis	Bean goose	3
Branta bernicla glaucogastra	Brant	3
Branta canadensis	Canada goose	6

BIRDS—continued

Anseriformes—Continued.

Branta canadensis hutchinsii	Hutchin's goose	4
Branta canadensis minima	Cackling goose	4
Branta canadensis occidentalis	White-cheeked goose	20
Branta leucopsis	Barnacle goose	1
Cairina moschata	Muscovy duck	3
Casarca variegata	Paradise duck	1
Cereopsis novaehollandiae	Cereopsis or Cape Barren goose	1
Chen atlantica	Snow goose	7
Chen caerulescens	Blue goose	9
Chenopis atrata	Black swan	1
Chloephaga leucoptera	Magellan goose	1
Cygnopsis cygnoides	Chinese goose	3
Cygnus columbianus	Whistling swan	3
Cygnus olor	Mute swan	2
Dafila acuta	Pintail duck	5
Dafila bahamensis	Bahaman pintail	1
Dafila acuta ×	Pintail hybrid	1
Dendrocygna arborea	Black-billed tree duck	5
Dendrocygna autumnalis	Black-bellied tree duck	4
Dendrocygna viduata	White-faced tree duck	1
Dendronessa galericulata	Mandarin duck	1
Leptotarsis eytoni	Eyton's tree duck	2
Mareca americana	Baldpate	2
Neochen jubata	Orinoco goose	2
Nesochen sandvicensis	Hawaiian goose	1
Nettion carolinense	Green-winged teal	1
Nyroca affinis	Lesser scaup	4
Nyroca americana	Redhead	1
Nyroca collaris	Ring-neck duck	1
Nyroca valisineria	Canvasback duck	2
Philacte canagica	Emperor goose	13
Plectropterus gambensis	Spur-winged goose	2
Querquedula cyanoptera	Cinnamon teal	1
Querquedula discors	Blue-winged teal	1
Sarkidiornis melanota	Comb duck	1
Tadorna tadorna	Shelldrake	1

Falconiformes:

Aegypius monachus	Cinereous vulture	1
Aquila chrysaetos	Golden eagle	2
Buteo borealis	Red-tailed hawk	4
Buteo lineatus	Red-shouldered hawk	1
Buteo platypterus	Broad-winged hawk	1
Buteo swainsoni	Swainson's hawk	1
Cathartes aura	Turkey vulture	3
Coragyps atratus	Black vulture	1
Falco albigularis	White-throated bat-falcon	1
Falco sparverius	Sparrow hawk	4
Gymnogyps californianus	California condor	3
Gypaetus barbatus grandis	Lammergeyer	1
Gyps rueppelli	Ruppell's vulture	1
Haliastur indus	Malay brahminy kite	1
Haliaeetus leucocephalus	Bald eagle	17

Falconiformes—Continued.

Hypomorphnus urubitinga	Brazilian eagle	1
Milvus migrans	Yellow-billed kite	1
Pandion haliaëtus carolinensis	Osprey or fish hawk	1
Polihierax semitorquatus	African pigmy falcon	5
Polyborus cheriway	Audubon's caracara	2
Polyborus plancus	South American caracara	1
Stephanoaetus coronatus	Crowned hawk-eagle	1
Torgos tracheliotus	African eared-vulture	1
Uroaetus audax	Wedge-tailed eagle	1
Vultur gryphus	South American condor	1

Galliformes:

Alectoris graeca	Greek partridge	2
Argusianus argus	Argus pheasant	2
Calophasis ellioti	Elliot's pheasant	1
Chrysolophus amherstiae	Lady Amherst's pheasant	3
Chrysolophus amherstiae × *Syrmaticus reevesi*	Hybrid	2
Chrysolophus pictus	Golden pheasant	4
Colinus virginianus	Bob-white	1
Crax globicera	Mexican curassow	1
Crax globulosa	Spix's wattled curassow	2
Crax panamensis	Panama curassow	1
Crossoptilon mantchuricum	Brown eared-pheasant	1
Gennaeus lineatus	Lineated pheasant	3
Gennaeus nycthemerus	Silver pheasant	2
Gennaeus nycthemerus bellii	Bell's silver pheasant	1
Hierophasis swinhoei	Swinhoe's pheasant	4
Lophophorus impeyanus	Himalayan Impeyan pheasant	2
Meleagris gallopavo	Domestic turkey	1
Mitu mitu	Razor-billed curassow	1
Mitu salvini	Salvini's curassow	1
Numida mitrata reichenowi	Reichenow's helmeted guinea fowl	3
Pavo cristatus	Blue peafowl	4
	White peafowl	1
Pavo muticus	Green peafowl	2
Penelope boliviana	Crested guan	1
Phasianus torquatus	Ring-necked pheasant	10
Syrmaticus reevesi	Reeve's pheasant	3

Gruiformes:

Anthropoides virgo	Demoiselle crane	4
Antigone antigone	Saras crane	1
Antigone australasiana	Australian crane	1
Balearica pavonina	West African crowned crane	1
Balearica regulorum gibbericeps	East African crowned crane	1
Eurypyga helias	Sun bittern	2
Fulica americana	Coot	1
Gallinula chloropus cachinnans	Florida gallinule	1
Grus canadensis tabida	Sandhill crane	1
Grus leucauchen	White-naped crane	1
Grus leucogeranus	Siberian crane	2
Limnocorax flavirostra	African black rail	3
Otis cafra	Denham's bustard	1

Gruiformes—Continued.

Otis cafra jacksoni	Jackson's bustard	1
Porphyrio melanotus	New Zealand mud hen	1
Porphyrio poliocephalus	Gray-headed porphyrio	2
Psophia crepitans	Gray-backed trumpeter	1

Charadriiformes:

Belonopterus cayennensis	South American lapwing	1
Haematopus ostralegus	European oyster catcher	2
Larus argentatus	Herring gull	3
Larus atricilla	Laughing gull	2
Larus delawarensis	Ring-billed gull	4
Larus novaehollandiae	Silver gull	49
Larus ridibundus	European gull	1
Philomachus pugnax	Ruff	2
Sarciophorus tectus	Black-headed plover	1

Columbiformes:

Caloenas nicobarica	Nicobar pigeon	1
Columba guinea	Triangular-spotted pigeon	1
Columba leucocephala	White-crowned pigeon	1
Columba leuconota	Tibetan pigeon	2
Columba palumbus	Wood pigeon	2
Columba sp	Archangel pigeon	2
Columba sp	Fan-tailed pigeon	2
Goura sclateri	Sclater's crowned pigeon	1
Leptotila rufaxilla	Scaled pigeon	1
Ocyphaps lophotes	Crested pigeon	1
Pterocles orientalis	Oriental sandgrouse	2
Streptopelia risoria	Ring-necked dove	6
Streptopelia senegalensis	East African ring-necked dove	2
Turtur risorius	Turtledove	4
Zenaidura macroura	West Indian dove	3

Cuculiformes:

Centropus sinensis	Sumatran coucal	1
Crotophaga ani	Ani or Savanna cuckoo	2
Cuculus canorus	European cuckoo	2

Psittaciformes:

Agapornis lilianae	Nyassa lovebird	2
Amazona albifrons	White-fronted parrot	4
Amazona amazonica	Orange-winged parrot	2
Amazona arausiaca	Bouquet's parrot	1
Amazona auropalliata	Yellow-naped parrot	7
Amazona farinosa	Mealy parrot	1
Amazona festiva	Festive parrot	1
Amazona leucocephala	Cuban parrot	1
Amazona ochrocephala	Orange-fronted parrot	3
Amazona ochroptera	Yellow-shouldered parrot	3
Amazona oratrix	Double yellow-headed parrot	5
Amazona ventralis	Santo Domingo parrot	1
Amazona viridigenalis	Red-crowned parrot	3
Anodorhynchus hyacinthinus	Hyacinthine macaw	1
Aprosmictus erythropterus	Crimson-winged paroquet	1
Ara ararauna	Yellow and blue macaw	4
Ara macao	Red, yellow, and blue macaw	4

BIRDS—continued

Psittaciformes—Continued.

Ara maracana	Illiger's macaw	4
Ara mexicana	Mexican green macaw	3
Ara severa	Severe macaw	1
Aratinga jendaya	Jenday conure	1
Aratinga holochlora	White-eyed parrot	2
Aratinga solstitialis	Yellow paroquet	2
Brotogeris jugularis	Tovi paroquet	2
Coracopsis nigra	Lesser vasa parrot	1
Cyanopsittacus spixi	Spix's macaw	3
Deroptyus accipitrinus	Hawk-head parrot	1
Eolophus roseicapillus	Roseate cockatoo	6
Eos reticulata	Blue-eared lory	2
Eos rubra	Red lory	1
Eupsittula aurea	Golden-crowned paroquet	1
Eupsittula canicularis	Petz's paroquet	2
Forpus guianensis	Green-rumped parrotlet	1
Kakatoe galerita	Sulphur-crested cockatoo	1
Kakatoe leadbeateri	Leadbeater's cockatoo	2
Kakatoe moluccensis	Great red-crested cockatoo	1
Kakatoe sulphurea	Lesser sulphur-crested cockatoo	1
Leptolophus novaehollandicus	Cockateel	2
Melopsittacus undulatus	Grass paroquet	26
Microglossus aterrimus	Great black cockatoo	1
Myopsitta monachus	Quaker paroquet	1
Nandayus nanday	Nanday paroquet	1
Nestor notabilis	Kea	4
Pionites xanthomera	Amazonian caique	2
Pionus menstruus	Blue-headed parrot	1
Psittacus erithacus	African gray parrot	1
Psittacus k. kremeri	Long-tailed paroquet	3
Psittacus nepalensis	Nepalese paroquet	1
Tanygnathus megalorhynchus	Great-billed parrot	1
Trichoglossus cyanogrammus	Green-naped lory	1
Trichoglossus forsteni	Forsten's paroquet	1
Trichoglossus novaehollandiae	Blue-bellied lory	1

Strigiformes:

Bubo virginianus	Great horned owl	5
Otus asio	Screech owl	1
Strix varia varia	Barred owl	7

Caprimulgiformes:

Chordeiles minor minor	Nighthawk	3

Coraciiformes:

Buceros rhinoceros	Rhinoceros hornbill	1
Bucorvus abyssinicus	Abyssinian ground hornbill	2
Dacelo gigas	Kookaburra	4
Dichoceros bicornis	Concave-casqued hornbill	2

Piciformes:

Aulacorhynchus erythrognathus	Venezuelan toucanette	1
Cyanops asiatica	Asiatic red-fronted barbet	1
Pteroglossus bitorquatus	Two-banded aracari	4
Ramphastos culminatus	White-breasted toucan	1
Ramphastos toco	Toco toucan	2

BIRDS—continued

Piciformes—Continued.

Selenidera culik	Guiana toucanette	2
Thereiceryx lincatus	Streaked barbet	1

Passeriformes:

Agelaius icterocephalus	Yellow-headed marsh bird	1
Amadina fasciata	Cut-throat finch	1
Amblyrhamphus holosericeus	Red-headed marsh troupial	1
Aphelocoma californica woodhousci	Woodhouse's jay	2
Calocitta formosa	Mexican magpie jay	1
Carduelis carduelis	European gold finch	1
Chasmorhynchus nudicollis	Naked-throated bell-bird	1
Cissa chinensis	Chinese cissa	2
Coliuspasser albonotatus	Yellow-shouldered whydah	1
Coliuspasser ardens	Red-necked whydah	4
Corvus albus	White-breasted crow	2
Corvus brachyrhynchos	American crow	2
Corvus corax sinuatus	American raven	1
Corvus coronoides	Australian crow	1
Corvus cryptoleucus	White-necked raven	9
Cosmopsarius regius	Splendid starling	3
Cyanerpes cyaneus	Blue honey-creeper	4
Cyanocorax chrysops	Pileated jay	2
Cyanocorax cyanopogon	White-naped jay	4
Dicrurus mirabilis	White-bellied drongo	1
Dissemurus paradiseus	Giant racquet-tailed drongo	1
Elathea jocosa	Red-eared bulbul	1
Fringilla montifringilla	Brambling finch	1
Galeopsar salvadorii	Crested starling	1
Gracula palawanensis	Palawan mynah	2
Gracula religiosa	Southern hill mynah	4
Gymnomystax mexicanus	Giant oriole	1
Icterus giraudi	Giraud's oriole	1
Kittacincla malabarica	Shama thrush	1
Lamprocolius sycobius	Southern glossy starling	1
Lanius dorsalis	Teita fiscal-shrike	2
Melanopteryx rubiginosus	Chestnut weaver	9
Molpastes haemorrhous	Black-headed bulbul	1
Momotus momotus parensis	Motmot	2
Padda oryzivora	White Java sparrow	2
Paradisea minor	Lesser bird-of-paradise	1
Paroaria cucullata	Red-crested or Brazilian cardinal	2
Pheucticus tibialis	Yellow grosbeak	1
Pica nuttalli	Yellow-billed magpie	4
Pica pica hudsonia	Magpie	7
Pitangus sulphuratus	Kiskadee flycatcher	3
Ploceus intermedius	Black-cheeked weaver	25
Pomatorhinus sp	Scimitar babbler	1
Psomocolax oryzivora	Rice grackle	1
Quelea sanguinirostris intermedia	Southern masked-weaver-finch	1
Seleucides niger	12-wired bird-of-paradise	2
Serinus canarius	Canary	19
Sicalis minor	Lesser saffron finch	1
Sporophila aurita	Hick's seedeater	5

Passeriformes—Continued.

Sporophila gutturalis	Yellow-bellied seedeater	2
Sporophila lineola	White-crowned seedeater	3
Steganura paradisea	Paradise whydah	2
Taeniopygia castanotis	Zebra finch	6
Tanagara fulvicrissa	Fulvous-vented euphonia	2
Tanagra luteicapilla	Yellow-crowned euphonia	9
Thraupis cana	Blue tanager	2
Tiaris canora	Melodius grassquit	2
Tiaris olivacea	Mexican grassquit	7
Turdus grayi	Bonaparte's thrush	1
Urocissa occipitalis	Red-billed blue magpie	2
Volatinia jacarini	Blue-black grassquit	4
Xanthocephalus xanthocephalus	Yellow-headed blackbird	3
Xanthoura luxuosa guatemalensis	Guatemala green jay	1
Xanthoura luxuosa sub. sp	Nicaragua green jay	1

REPTILES

Chelonia:

Amyda ferox	Soft-shelled turtle	7
Chelodina longicollis	Australian snake-necked turtle	5
Chelydra osceola	Florida snapping turtle	1
Chelydra rossignonii	Rossignon's snapping turtle	1
Chelydra serpentina	Snapping turtle	8
Chrysemys picta	Painted turtle	2
Clemmys guttata	Spotted turtle	1
Clemmys insculpta	Wood turtle	3
Clemmys muhlenbergii	Muhlenberg's tortoise	1
Cyclemys amboinensis	Malayan box turtle	1
Gopherus agassizii	Agassiz's tortoise	1
Hydromedusa tectifera	South American snake-necked turtle	4
Kinosternon flavescens	Musk turtle	1
Kinosternon subrubrum	Musk turtle	6
Macrochelys temminckii	Alligator snapping turtle	1
Malaclemmys centrata	Diamond-back terrapin	11
Pelomedusa galeata	Common African water-tortoise	2
Platemys platycephala	Flat-headed turtle	1
Podocnemis expansa	South American river-tortoise	1
Pseudemys concinna	Cooter	7
Pseudemys decussata	Haitian tortoise	1
Pseudemys elegans	Cumberland terrapin	2
Pseudemys floridana	Florida terrapin	6
Pseudemys pseudogeographica	False geographic turtle	1
Pseudemys rugosus	Cuban turtle	1
Terrapene carolina	Box tortoise	20
Terrapene major	Florida box turtle	2
Terrapene ornata	Ornate box tortoise	2
Testudo elephantina	Elephant tortoise	2
Testudo ephippium	Duncan Island tortoise	7
Testudo hoodensis	Hood Island tortoise	2
Testudo pardalis	Leopard tortoise	1
Testudo radiata	Radiated tortoise	1

REPTILES—continued

Chelonia—Continued.

Testudo tabulata	South American tortoise	1
Testudo torneri	Soft-shelled land tortoise	1
Testudo vicina	Albemarle Island tortoise	1

Crocodilia:

Alligator mississipiensis	American alligator	30
Caiman sclerops	Spectacled caiman	3
Crocodylus acutus	American crocodile	1
Crocodylus cataphractus	West African crocodile	1
Crocodylus palustris	Marsh crocodile or mugger	1
Crocodylus porosus	Salt water crocodile	2
Osteolaemus tetraspis	Broad-nosed crocodile	1

Lacertilia:

Agama stellio	Agama lizard	2
Anolis carolinensis	False chameleon	16
Anolis equestris	Giant anolis	8
Anolis porcatus	Cuban anolis	2
Basiliscus vittatus	Banded basilisk	1
Cnemidophorus sexlineatus	Six-lined lizard	1
Coleonyx sp	Coleonyx lizard	1
Conolophus subcristatus	Galapagos iguana	1
Crocodilurus lacertinus	Crocodile lizard	4
Crotaphytus collaris	Collared lizard	1
Cyclura cornuta	Rhinoceros iguana	1
Dracaena guianensis	Dragon lizard	2
Eumeces faciatus	Blue-tailed skink	2
Eumeces obsoletus	Brown skink	1
Gerrhosaurus validus	Robust plated lizard	1
Heloderma horridum	Beaded lizard	2
Heloderma suspectum	Gila monster	5
Leiocephalus cubensis	Cuban curl-tailed lizard	18
Ophisaurus ventralis	Glass snake	2
Phrynosoma cornutum	Horned lizard	1
Phrynosoma platyrhinos	Horned lizard	3
Physignathus lesueurii	Lesueur's water dragon	1
Plica plica	Plicated lizard	1
Sceloporus magister	Western spiny lizard	2
Sceloporus undulatus	Fence lizard	4
Tiliqua nigrolutea	Mottled lizard	1
Tiliqua scincoides	Blue-tongued lizard	2
Trachysaurus rugosus	Stump-tailed lizard	3
Tupinambis nigropunctatus	Tegu lizard	2
Urocentron azureum	Urocentron lizard	1
Uta stansburiana	Stansbury's lizard	1
Varanus gouldii	Gould's monitor	4
Varanus komodoensis	Komodo dragon	1
Zonurus giganteus	Spiny lizard	1

Ophidia:

Abastor erythrogrammus	Hoop snake or rainbow snake	1
Agkistrodon mokasen	Copperhead snake	2
Agkistrodon piscivorus	Water moccasin	4
Alsophis angulifer	Jubo or Culebra snake	4
Bitis arietans	Puff adder	3

Ophidia—Continued.

Boa canina	Green tree boa	2
Boa cookii	Cook's tree boa	1
Boiga dendrophila	Mangrove snake	1
Coluber c. constrictor	Black snake	2
Constrictor constrictor	Boa constrictor	1
Constrictor mexicana	Mexican boa	1
Crotalus adamanteus	Diamond-back rattlesnake	3
Crotalus cerastes	Sidewinder rattlesnake	1
Crotalus confluentus	Western rattlesnake	1
Crotalus horridus	Banded rattlesnake	1
Drymarchon corais cooperi	Indigo snake	2
Elaphe guttata	Corn snake	2
Elaphe laeta	Emory's snake	3
Elaphe obsoleta obsoleta	Pilot snake	2
Elaphe quadrivittata	Chicken snake	2
Elaphe vulpina	Fox snake	1
Epicrates angulifer	Cuban tree boa	2
Epicrates cenchris	Rainbow boa	12
Eryx johni	Sand boa	1
Eunectes murinus	Anaconda	4
Farancia abacura	Horn snake	1
Heterodon contortrix	Hog-nosed snake	1
Lampropeltis g. getulus	King or chain snake	2
Lampropeltis getulus holbrooki	Holbrook's king snake	2
Lampropeltis t. triangulum	Milk snake	1
Leimadophis andreae	Jubito or magdalena snake	1
Leptodira albofusca	Common tree snake	1
Liopeltis sp	Green snake	1
Masticophis f. flagellum	Coachwhip	2
Naja flava	Golden cobra	1
Naja tripudians	Indian cobra	1
Naja tripudians sumatrana	Sumatran black-headed cobra	1
Natrix cyclopion	Water snake	1
Natrix sp	Water snake	5
Opheodrys aestivus	Rough-scaled green snake	2
Phrynonax sulphureus	South American rat snake	1
Pituophis melanoleucus	Bull snake	1
Pituophis sayi	Pine snake	2
Python molurus	Indian python	1
Python regius	Ball python	1
Python reticulatus	Regal python	4
Sistrurus catenatus catenatus	Massasauga rattlesnake	2
Thamnophis sauritus proximus	Garter snake	1
Thamnophis sirtalis	Garter snake	3
Tretanorhinus variabilis	Cuban water snake	1
Trimeresurus monticola	Mountain pit viper	1

AMPHIBIANS

Caudata:

Amphiuma means	Blind eel or congo snake	1
Amphiuma tridactylum	Blind eel or congo snake	1
Cryptobranchus alleganiensis	Hellbender	7

<div align="center">AMPHIBIANS—continued</div>

Caudata—Continued.

Salamandra salamandra	Fire salamander	7
Triturus pyrrhogaster	Red-bellied Japanese newt	6
Triturus viridescens	Common newt	18

Salientia:

Atelopus varius cruciger	Yellow atelopus	2
Atelopus v. varius	Red, yellow, and black atelopus	7
Bombina bombina	Bell toad	4
Bufo alvarius	Green toad	5
Bufo americanus	Common American toad	2
Bufo empusus	Sapo de concha	15
Bufo fowleri	Fowler's toad	1
Bufo marinis	Marine toad	6
Bufo peltocephalus	Cuban giant toad	1
Ceratophrys dorsata	Horned toad	3
Dendrobates auratus	Arrow-poison frog	37
Dendrobates minutus	Golden-striped frog	2
Dendrobates pumilio	Red dendrobates	5
Hyla caerulea	Australian tree frog	6
Hyla crucifer	"Spring peeper" tree frog	4
Hyla septentrionalis	Cuban tree frog	20
Pipa americana	Surinam toad	1
Rana catesbeiana	Bullfrog	5
	Bullfrog (albino)	1
Rana clamitans	Green frog	1
Rana grylio	Southern bullfrog	3
Rana palustris	Pickerel frog	1
Rana sphenocephala	Southern leopard frog	1
Xenopus mulleri	Muller's clawed frog	2

<div align="center">FISHES</div>

Acanthopthalmus kuhlii		5
Barbus sp		8
Betta splendens	Siamese fighting fish	1
Brachydanion rerio	Zebra fish	5
Corydoras aeneus	Trinidad armored catfish	3
Corydoras melanistius	Armored catfish	1
Electrophorus electricus	Electric eel	2
Helostoma temminckii	Kissing gourami	2
Hemigramimus unilineatus		1
Heterandria formosa		8
Hyphessobrycon bifasciatus	Yellow characin	1
Hypostomus sp	Armored catfish	2
Jordanella floridae	American flag fish	9
Kryptopterus bicirrhus	Glass catfish	4
Lebistes reticulatus	Guppy	50
Lepidosiren paradoxa	South American lungfish	3
Leporinus fasciatus		1
Malopterurus electricus	Electric catfish	1
Monocirrhus polyacanthus	Leaf fish	2
Pantodon buchholzi	Butterfly fish	1
Platypoecilus maculatus	Goldplaties	40
Pristella riddlei		12

FISHES—continued

Protopterus annectens	African lungfish	2
Pterophyllum scalare	Angel fish	3
Rasbora heteromorpha		12
Trichogaster trichopterus	Three-spot gourami	3
Xiphophorus hellerii	Swordtail	2

ARACHNIDS

Eurypelma sp	Tarantula	1
Latrodectus mactans	Black widow spider	1
Mastigoproctus giganteus	Vinegarone or whip scorpion	1

INSECTS

Blabera sp	Giant cockroach	20
Pogonomyrmex badius	Agricultural ant	1 colony

MOLLUSKS

Achatina variegata	Giant land snail	2

CHILOPODA

Scolupendra sp	Giant centipede	1

CRUSTACEA

Cardisoma guanhumi	Great land crab	2

Respectfully submitted.

W. M. MANN, *Director.*

Dr. C. G. ABBOT,
   Secretary, Smithsonian Institution.

APPENDIX 7

REPORT ON THE ASTROPHYSICAL OBSERVATORY

Sir: I have the honor to submit the following report on the activities of the Astrophysical Observatory for the fiscal year ended June 30, 1936:

As heretofore, our principal work has been the determination of the variability of the intensity of the sun's radiation as it would be found outside of our atmosphere; i. e., changes in the so-called solar constant of radiation. Measurements of the solar constant of radiation have been continued daily when possible at three stations: Table Mountain, Calif., Montezuma, Chile, and Mount St. Katherine, Egypt. Although to the eye the sky at Table Mountain seems equally as favorable to the work as that at the two foreign stations, the measurements at Table Mountain show much greater irregularity. Days that appear excellent there sometimes yield solar-constant values which are quite impossible. We suppose this is caused by invisible clouds of water vapor sweeping over the station through the canyons of the Sierra Madre Mountains.

We have attempted in the past year to develop a criterion based on the measurements which should inform us, before reducing an observation, whether it is affected by this invisible prejudicial sky condition, and in this search we have measurably succeeded. Finding it so useful for Table Mountain work, we have applied it also to the work of Montezuma and Mount St. Katherine, where much less frequently than at Table Mountain the results are similarly inexplicably bad. These investigations have occupied Mr. Aldrich and several computers at Washington for most of the year, but are now completed. They lead to a recomputation of all solar-constant measurements of recent years at all stations—a heavy task now under way.

Of the criterion itself, its technical character forbids a full description here. In brief, it comprises constructing families of standard curves representing average relationships of pyrheliometry to pyranometry at different air masses and different values of precipitable water. When the observations on any occasion depart from these standard curves beyond a certain tolerance, such observations are to be viewed with suspicion. In this way single observations of a given day may be rejected from the mean of the day. Also, suspicious days

at one station may be justifiably rejected, because of this sort of internal evidence, when they differ widely from reasonable results of other stations. The application of these criteria at the three stations will lead to a new increase in the accuracy with which we may measure the solar variability, and to a much closer agreement between the results of the three stations.

This long-desired improvement in accuracy is now shown to be indispensable to a proposed application of studies of solar variability to weather forecasting.

Dr. Abbot published in May and August of 1936 two papers entitled, respectively, "The Dependence of Terrestrial Temperatures on the Variations of the Sun's Radiation" and "Further Evidence on the Dependence of Terrestrial Temperatures on the Variations of Solar Radiation." These papers appear to prove that the short-interval changes of solar radiation, such as run their courses in a few days, are of major influence on the weather for the ensuing 2 weeks or more. Figure 2 of the first-mentioned paper shows such effects for the temperature of Washington. The curves shown each represent the average results for some 10 to 20 cases occurring in each of the months of the year of the years 1924–1935.

It is observed that opposite solar changes produce opposite temperature effects; that these effects differ from month to month; that other investigations reported in the papers cited show that they also differ from locality to locality; that the effects are of large magnitude, sometimes reaching 15° F., sufficient indeed to account for most variations from the normal temperature; that these effects follow solar changes seldom as great as 1.5 percent and averaging only about 0.7 percent.

After discussion of these results with the Chief of the United States Weather Bureau and with several gentlemen of the Weather Bureau Advisory Committee, these gentlemen all agreed that the investigations offered reasonable promise of a method of forecasting some features of the weather for at least 2 weeks in advance. They unitedly signed a memorandum recommending increased support to the Astrophysical Observatory to enable it to set up seven additional solar stations in the best localities of the world, and also to investigate the possibility of automatic determinations of solar variability from sounding balloons. This measure was approved by the President and the Bureau of the Budget, passed the Senate as an amendment to the Urgent Deficiency Act, but was rejected in conference with the House.

The Institution has since made a small grant from private funds to promote preliminary studies for the balloon investigation referred to, but the application of solar variation observations to weather fore-

casting must await Government support. The necessary expense will approximate $200,000 a year. It is necessary to observe the complete solar radiation of all wave lengths nearly every single day to an accuracy of ⅕ of a percent at mountain solar-constant stations, or else to observe daily the intensity of a certain band of ultraviolet solar rays from sounding balloons at an altitude of 100,000 feet or more, with an accuracy of 2 percent or better. Either plan involves difficulty and expense, but the probable advance in weather forecasting seems to justify it.

In August 1935 Dr. Abbot published a study of the variation found in the monthly mean values of the solar constant of radiation since the year 1920. This was entitled "Solar Radiation and Weather Studies." The following conclusions are quoted from the summary:

1. The output of radiation of the sun varies, as proved by simultaneous observations at three stations remote from each other.

2. The solar variation, seemingly irregular, really comprises 12 or more regular periodicities, which support successful predictions of solar changes for years in advance.

11. Forecasts based on these relations having been made to cover the years 1934, 1935, and 1936 for more than 30 stations in the United States, these forecasts are fairly well verified both as to temperature and precipitation in 1934.

Although, as stated in conclusion 11, fair success was achieved in the predictions for the year 1934, the success was less complete in 1935 and 1936. Weather details, though present, were found to be displaced in time so much as to invalidate the method for detailed predictions more than a year in advance. This partial failure is believed to be caused by the changes of phase of the subordinate periodicities which make up the 23-year cycle. It is hoped that further study may give means of predicting these changes of phase, and so of perfecting the method.

But while the prediction of details is thus unsatisfactory, certain large and prolonged features, like the great drought in the Northwest, seem to be very clearly previsioned by the cycle. This appears plainly in the accompanying figure 1, a reproduction of figure 26B of the article. It is very plain that the first decades of each of the five 23-year cycles shown there were marked by the fall of the level of Lake Huron, but that this depression in the first, third, and fifth cycles is outstanding. Thus there seems to be a 46-year cycle of great droughts, and while moderate drought conditions may be expected in the decade 1950–1960, a severe drought is probable in the decade 1975 to 1985.

The present drought seems comparable to those of the decades following 1840 and 1890, and may therefore be expected to last for a year, or possibly 2 years more before the initiation of recovery. But it would be rash to make a more definite prediction.
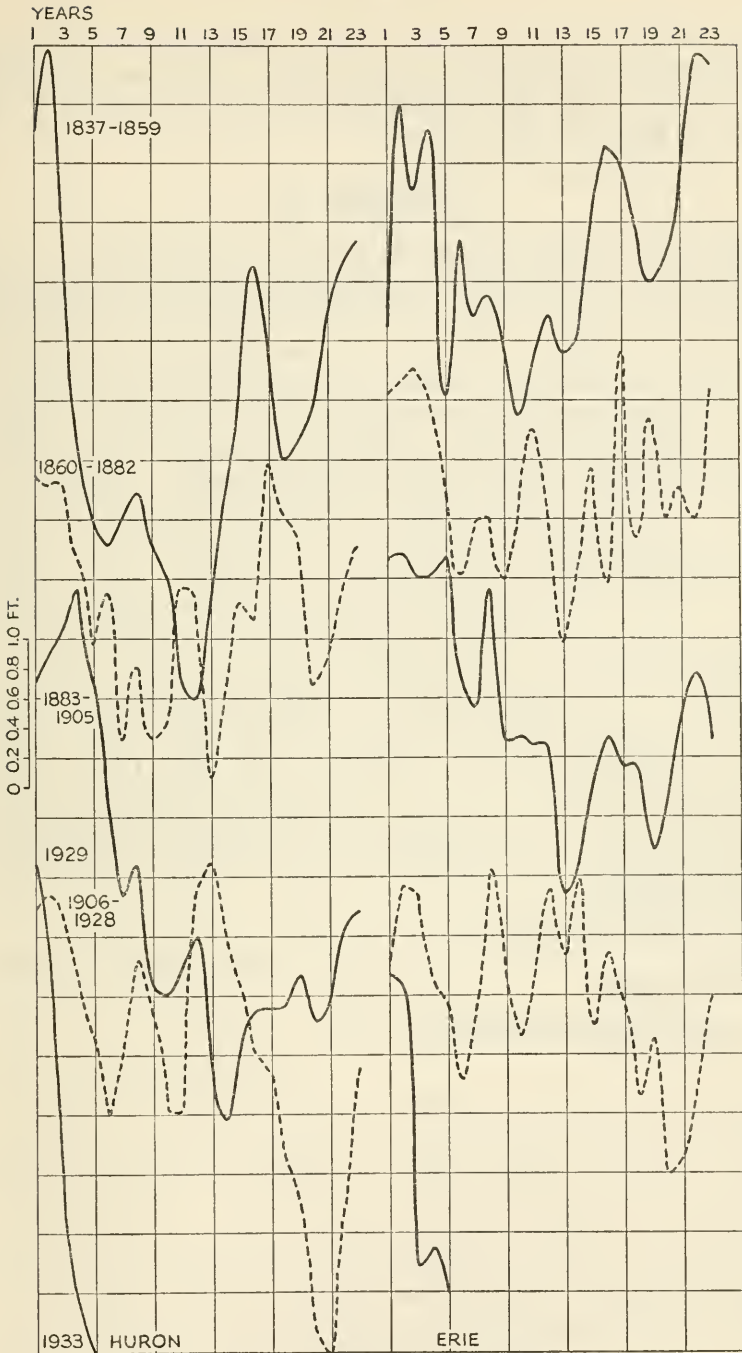
FIGURE 1.—Levels of Great Lakes, 23-year cycles. Note the marked subsidence culminating after 11 years in the full curves.

PERSONNEL

No changes of personnel have occurred other than the shifting of observers from one field station to another, except that on April 16, 1936, Alfred G. Froiland reported as bolometric assistant to take station at Mount St. Katherine.

SUMMARY

The year has been distinguished for the introduction of a new criterion for distinguishing unsatisfactory sky conditions at the solar-constant stations. This will add decidedly to the accuracy and harmony of the results. Studies of the variability of the sun over an interval of 15 years have disclosed many periodicities, all aliquot parts of 23 years, which altogether make up the apparently irregular solar variation of long term. The cycle of 23 years is abundantly evidenced in weather and things dependent thereon. Besides this it is shown that the weather is to a great extent governed for at least 2 weeks afterward by the initiation of incidental rising or falling solar radiation, usually of only a few days' duration. Expert opinion concurs that this affords a promising method of forecasting certain weather features for at least 2 weeks in advance. Unfortunately, it requires expansions of our solar-observation program, which thus far there are no funds to finance. Papers detailing these investigations were published by the Director in the Smithsonian Miscellaneous Collections under the following titles: "The Dependence of Terrestrial Temperatures on the Variations of the Sun's Radiation", "Further Evidence on the Dependence of Terrestrial Temperatures on the Variations of Solar Radiation", and "Solar Radiation and Weather Studies."

Respectfully submitted.

C. G. ABBOT, *Director.*

The SECRETARY,
 Smithsonian Institution.

APPENDIX 8

REPORT ON THE DIVISION OF RADIATION
AND ORGANISMS

Sir: I have the honor to submit the following report on the activities of the Division of Radiation and Organisms during the year ended June 30, 1936:

This has been a year of large accomplishment in several fields. Mr. Hoover's work on the dependence of carbon dioxide assimilation in wheat on wave length of radiation has been amplified and rounded out for publication. This pioneering research has produced and checked a curve which gives the efficiency of the different-colored rays to promote photosynthesis. The curve starts at zero in the violet, runs to a maximum in the blue at about 4,400 A, continues of moderate intensity in the green and yellow, rises to its highest maximum in the red at 6,500 A, and then falls to zero.

Dr. Meier has continued her experiments on the effects of ultraviolet rays on algae. Besides checking former work and publishing on lethal effects, she has shown that ultraviolet rays of maximum lethal influence when applied in minute doses are stimulating. This behavior reminds us of the effects of certain poisonous drugs which in minute doses are stimulants.

Dr. Johnston has continued experiments on the effects of light of different wave lengths to promote growth effects of various kinds in tomatoes. His work has yielded much advance in the technique of these investigations. Among other results which stand out clearly, he finds that rest periods not only from radiation but of diminished temperature are necessary to these plants.

He gave the annual Arthur Lecture on the subject of the influences of the sun on plant growth.

Dr. McAlister has developed an extremely sensitive and quick-acting spectroscopic method for measuring carbon dioxide concentration. A concentration of 1/10,000 of 1 percent carbon dioxide in air is readily measured. The respiration and carbon dioxide assimilation of a single grain of wheat in its germination is readily observed. Studies of the dependence of photosynthesis in wheat on time factors are in progress and are yielding beautiful and remarkable results. Dr. McAlister also did interesting cooperative work with the Department of Agriculture on the germination of seeds.

Mr. Clark has made valuable developments in the technique of special lights useful for studies of plant growth. He has also made important improvements in thermoelectric junction material, having developed a couple of high sensitiveness and at the same time as rugged as ordinary wires of common metals of equal size. With Mr. Fillmen he has constructed much new apparatus for the uses of the Division.

The work finished or in hand will shortly afford publications of great interest to plant physiologists and others. Individuals of the Division have been of utmost value to the Astrophysical Observatory and other branches of the Institution, assisting in special problems.

Respectfully submitted.

C. G. ABBOT, *Director.*

The SECRETARY,
　Smithsonian Institution.

APPENDIX 9

REPORT ON THE LIBRARY

Sir: I have the honor to submit the following report on the activities of the Smithsonian library for the fiscal year ended June 30, 1936:

THE LIBRARY

The Smithsonian library, or library system, comprises 10 major and 35 minor units, each an important instrument in the work of the Institution or of one of its affiliated bureaus. They are as follows: The main library, or the Smithsonian deposit in the Library of Congress—a collection which, while somewhat general in character, is chiefly scientific and technical and contains extensive files of monographs and serials, American and foreign, including the reports, proceedings, and transactions of many learned societies and institutions; the library of the United States National Museum, which also concerns itself largely with natural history and technology, and has more or less closely connected with it the 35 sectional libraries of administration, administrative assistant's office, agricultural history, anthropology, archeology, biology, birds, botany, echinoderms, editor's office, engineering, ethnology, fishes, foods, geology, graphic arts, history, insects, invertebrate paleontology, mammals, marine invertebrates, medicine, minerals, mollusks, organic chemistry, paleobotany, photography, physical anthropology, property clerk's office, reptiles and batrachians, superintendent's office, taxidermy, textiles, vertebrate paleontology, and wood technology; the library of the Bureau of American Ethnology, concerned with the history, life, and culture of the early peoples of the Americas, notably the North American Indians; the library of the Astrophysical Observatory, on astrophysics and meteorology; the library of the Freer Gallery of Art, related to the special interests of the Freer Gallery, namely, the art and culture of the Far East, India, Persia, and the nearer East, and the art of James McNeill Whistler and other American painters, and containing the celebrated Biblical manuscripts of the fourth and fifth centuries, known as the Washington Manuscripts; the library of the National Gallery of Art, on the fine arts of Europe and America; the Langley aeronautical library—the famous collection of aeronautical publications, many of them very rare, that once belonged to Samuel Pierpont Langley,

Alexander Graham Bell, Octave Chanute, and James Means, and that since 1930, under its own name and book plate, has supplemented the Government collection on aeronautics in the Library of Congress; the Smithsonian office library, made up of general reference works, publications of the Institution and its branches as well as of various foreign learned societies and institutions, and a large number of popular books and magazines; the radiation and organisms library, pertaining to the studies the Institution is making of the influence of the sun on plant and animal life; and the library of the National Zoological Park, on animals and their care.   In the libraries taken together there are about 860,000 volumes, pamphlets, and charts.   This total does not include thousands of volumes awaiting completion, binding, and cataloging.

<center>PERSONNEL</center>

Four changes took place in the permanent staff during the year.

Miss Ella Leary, after a long service as librarian of the Bureau of American Ethnology, retired, and Miss Miriam B. Ketchum was transferred to the vacancy from the library of the Weather Bureau. Miss Ketchum received the B. A. and M. A. degrees from George Washington University, where two of her special interests were library science and anthropology.   Before her appointment to the Weather Bureau in 1934 she served for some years on the library staff of the Naval Observatory.

Mrs. Grace A. Parler, who since 1930 had been in immediate charge of the library of the Freer Gallery of Art, resigned.   She was succeeded by Miss Alice Elizabeth Hill, who had taken the B. A. degree at American University, studied library science in George Washington University, and obtained considerable experience at various times as a temporary employee of the Smithsonian library.

Miss Ruth E. Blanchard, a graduate in library science of the University of Oklahoma and for several years a member of the library staff of the university, was appointed to the position of minor library assistant in the Astrophysical Observatory, under an arrangement, however, by which part of her salary is paid by the National Zoological Park and part of her time given to its library.

Stephen Stuntz, who for 6 years had been assistant messenger, was promoted to a post elsewhere in the Institution, and the vacancy was filled by the selection of Carroll McKinley Martin.

The temporary assistants were Miss Margaret Link, Miss Helen Rankin, Miss Wilda Suter, and Mrs. Emma B. Thomsen.   A number of workers under the F. E. R. A. were also assigned to the library for a time early in the year and toward its close several under the W. P. A.

As usual, although some of the accessions for the year were presented by friends of the Smithsonian or were purchased, most of them came in exchange for the publications of the Institution and its branches. The packages received by mail numbered 21,808 and through the International Exchange Service 2,368—an increase of 1,920 over the previous year. Especially noteworthy were the sendings from the R. Deputazione di Storia Patria per le Provincie di Romagna, Bologna; the Academia Română, Bucharest; the Carlisle Natural History Society, Carlisle; the Erdélyi Múzeum, Cluj; the Instituto Nazionale di Ottica, Firenze; the Naturforschende Gesellschaft zu Leipzig, Leipzig; the Société Géologique de Belgique, Liège; the Isle of Wight Natural History and Archaeological Society, Newport; the Nigerian Field Society, Ondo; the R. Laboratorio Centrale di Idrobiologia, Rome; the Fauna och Flora, Stockholm; the Botanisches Institut, Franz-Josefs Universität, Szeged; the Knox Academy of Arts and Sciences, Thomaston; the Japanese Pathological Society, Tokyo; and the Instytut Popierania Nauki, Warsaw. More detailed mention should be made of two sendings—one that of 41 monographs and bulletins, from the Oriental Institute, Chicago; the other of 156 publications—some long since out of print—from the Museum of Comparative Zoölogy, Cambridge. The last two sendings were obtained by the library under a special exchange arrangement, the latter by returning to Harvard some of the university's publications that had found their way into the Smithsonian duplicate collection. These many unusual sendings added materially to the resources of the Smithsonian deposit and the library of the National Museum.

Among the publications received were 7,021 dissertations from the Academy of Freiberg, the Agricultural School of Bonn-Poppelsdorf, the universities of Basel, Berlin, Bern, Bonn, Breslau, Budapest, Erlangen, Freiburg, Giessen, Greifswald, Halle, Heidelberg, Jena, Johns Hopkins, Kiel, Köln, Leipzig, Lund, Marburg, Neuchâtel, Pennsylvania, Rostock, Tübingen, Utrecht, Würzburg, and Zürich, and the technical schools of Berlin, Braunschweig, Delft, Dresden, Karlsruhe, and Zürich.

In connection with the exchange and other activities of the library the staff wrote 2,651 letters, or 516 more than the year before, arranged for 300 new exchanges, or 36 more than in 1935, and obtained, in response to 584 request cards, 6,422 volumes and parts needed in the libraries of the Institution. It should be pointed out, however, that, thanks to the recent organization of the Smithsonian duplicates, many of these publications were found in this collection—a fact that was particularly true of the large number sent to the Smithsonian deposit

and the libraries of the Astrophysical Observatory, Bureau of American Ethnology, and National Museum. Several thousand documents of foreign governments were forwarded by the library, as usual, to the division of documents in the Library of Congress.

GIFTS

Among the gifts of the year at least two were notable. They were the collections—each numbering many thousands—of publications on invertebrate paleontology and orthoptera gathered, respectively, during a long period of service in the National Museum by Dr. E. O. Ulrich and the late Dr. A. N. Caudell and presented, each with a complete card index, by Dr. Ulrich and Mrs. Caudell. It is gratifying to know that these unique and valuable semiprivate libraries are not to be dispersed but are to remain permanently as instrumentalities of research in the sections where they have grown up. A similar collection—or, at least part of it—namely, that of the late Dr. Walter Hough on anthropology, also became the property of the library during the year. Special mention should be made, too, of the gift of a generous number of its own publications from the Philosophical Society of Washington, to be used by the library for exchange purposes. Other large gifts were received from the Bureau of the International Catalogue of Scientific Literature, the American Association for the Advancement of Science, the Geophysical Laboratory of the Carnegie Institution, the Anthropological Society of Washington, and the Washington Academy of Sciences, as well as from the estate of the late Dr. W. L. Abbott and from W. P. Hay, son of the late Dr. O. P. Hay. One of the most welcome gifts came from the Library of Congress. It was a complete set—the fourth presented to the Institution—of printed cards covering the publications of the Smithsonian and its bureaus, for filing in the sectional catalogs of the Museum. The smaller gifts included Contribution à l'étude des Pilons Océaniens, by His Excellency Governor L. J. Bouge, of Guadeloupe, from the author; Zoologische Ergebnisse einer Reise nach Bonaire, Curaçao und Aruba im Jahre 1930, 3 volumes, from Dr. P. W. Hummelinck; Beiträge zur Mineralogie von Japan, by T. Wada, from T. Ito; Charles F. Dowd, by Charles N. Dowd, from Ralph W. Lester; Japanese Works of Art, 6 volumes, selected from the Moslé Collection, from Alexander G. Moslé; Moss Flora of North America North of Mexico, volume II, parts 1–3, by A. J. Grout, from the author; Back to Newton, a Challenge to Einstein's Theory of Relativity, by George de Bothezat, from the author; The Microscope and Its Revelations, by William B. Carpenter, Atlas der Diatomaceen-kunde, by Adolf Schmidt, and Diatommentafeln Zusammen-

gestellt für Einige Freunde—from Mrs. John V. C. Parker, from the library of her father, the late Stephen S. Day; Hunting Wild Life with Camera and Flashlight, 2 volumes, by George Shiras, 3d, from Dr. Gilbert Grosvenor; Cumulative Index to the National Geographic Magazine, 1899 to 1934, Inclusive, 2 copies, from the National Geographic Society; Cyrus Hall McCormick, volume 2 (2 copies), by William T. Hutchinson, from the McCormick Historical Association; A History of the College of Charleston, by J. H. Easterby, from the college; 26 reports on the work of the *Discovery*, from Dr. Stanley Kemp, director; 7 volumes of collected works on hydroids, from Mrs. C. C. Nutting; Biographical Memoir of Joseph Saxton, by Joseph Henry, from J. S. Pendleton; Collected Papers of Dr. George J. Conley, edited by Yale Castlio, and Principles of Osteopathy, by Yale Castlio, from the Kansas City College of Osteopathy and Surgery.

There were also gifts from Secretary Abbot, Assistant Secretary Wetmore, Mrs. Charles D. Walcott, and the following other members, associates, and friends of the Smithsonian staff: L. B. Aldrich, Dr. E. A. Chapin, A. H. Clark, Dr. D. M. Cochran, W. L. Corbin, F. E. Fowle, Dr. Herbert Friedmann, J. E. Graf, L. C. Gunnell, Mrs. Walter Hough, A. H. Howell, Dr. Aleš Hrdlička, N. M. Judd, G. D. McCoy, Mrs. C. L. Manning, Dr. W. C. Mansfield, Dr. W. M. Maxon, G. S. Miller, Jr., Dr. Harold Morrison, C. F. W. Muesebeck, Dr. G. S. Myers, P. H. Oehser, R. G. Paine, Dr. M. J. Rathbun, J. H. Riley, Dr. W. L. Schmitt, F. M. Setzler, R. E. Snodgrass, and W. P. True.

SOME STATISTICS

The accessions may be summarized as follows:

Library	Volumes	Pamphlets and charts	Total
Astrophysical Observatory	99	150	249
Bureau of American Ethnology	99	--------	99
Freer Gallery of Art	365	119	484
Langley Aeronautical	38	14	52
National Gallery of Art	314	236	550
National Museum	1,669	966	2,635
National Zoological Park	84	14	98
Radiation and Organisms	9	2	11
Smithsonian deposit, Library of Congress	3,456	3,401	6,857
Smithsonian office	166	14	180
Total	6,299	4,916	11,215

According to data available at the close of the year for the various libraries of the Institution, the number of publications cataloged was approximately 7,015; of cards prepared and filed, 55,829; of periodicals entered, 25,205; of loans made, 11,235, of which 281 were

to libraries outside of the Smithsonian system. The number of items borrowed from the Library of Congress was 2,330, and from other libraries 484.

The following will show the work done on the union catalog:

Volumes cataloged_____ 4,397
Pamphlets and charts cataloged_____ 2,423
New serial entries made_____ 195
Typed cards added to catalog and shelf list_____ 6,415
Library of Congress cards added to catalog and shelf list_____ 18,749

SPECIAL ACTIVITIES

Among the special activities of the year, a few may be mentioned as indicating further progress toward making the library system a more complete and efficient instrument in the work of the Institution and its branches.

The slow and tedious task of sorting, arranging, and labeling the large collection of miscellaneous material, including many thousands of scientific and technical serials, that had accumulated for years on the second and third floors of the west stacks of the Smithsonian Building—an undertaking referred to in several annual reports as receiving special attention—was at last practically finished, with the gratifying result that, as in 1934 and 1935, hundreds of publications were brought to light that were needed in the libraries of the Institution. It is hoped that the unchecked material on the first floor can receive similar treatment during the coming year, in connection particularly with the reorganization of the office library and the rearrangement, and possible reassignment, of the Watts de Peyster collection.

The staff sorted and arranged the 7,000 and more publications that were recently given to the library by the International Catalogue of Scientific Literature, selecting 1,019 for the National Museum, 108 for the Astrophysical Observatory, and 235 for the Smithsonian deposit. Most of these found their way into the active sets; the others into the reserve file—a collection, begun a year or two ago, of standard scientific works designed to meet the future requirements of the Institution. To this file will probably be added many of the remaining items, especially some of the longer runs, in this noteworthy gift. It is expected that permanent shelf room will be provided for the reserve collection in the west end of the Smithsonian Building when disposal is made of the duplicates now occupying this space.

The staff also continued the task of reorganizing the technological library and several of the sectional libraries, notably that of administration, in the Arts and Industries Building; advanced the work of classifying the Bell aeronautical clippings; withdrew 913 reprints and sep-

arates from the natural history library and sent them to the curators concerned; sorted according to subject the set of 27,200 printed cards covering to date the publications of the Institution and its branches, that was presented during the year by the Library of Congress, and forwarded them to the sectional libraries for filing; picked out 603 surplus maps from the collection in the National Museum and transferred them to the Smithsonian deposit, where they would be preserved against possible future need; prepared 300 volumes for the bindery, to be sent early in July as the first installment of several thousand publications to be bound with the deficiency appropriation made to the Smithsonian for this purpose toward the close of the fiscal year; checked and rearranged the reference collection in the office library; continued to date the index of Smithsonian publications and contributed substantially to the index of exchange relations; brought nearly to completion the seven library sets of Smithsonian publications—a piece of work that has required years of special search for missing items, many long since out of print; and finished cataloging the Chinese and Japanese publications in the library of the Freer Gallery of Art, as well as the field collection that had been returned to the Gallery from China the year before.

They sent back to the Superintendent of Documents a large number of Government publications that either were duplicates or were not pertinent to the work of the Institution; turned over many thousands of other items not in the immediate field of Smithsonian interest to the libraries of the Army Medical Museum, Department of Agriculture, Office of Education, and Geological Survey, and the Public Library of the District of Columbia; assisted further the American Association for the Advancement of Science in its effort, begun the year before and shared in at that time by the library, to complete its office set of Science by presenting to the Association 448 more numbers of this publication; made generous sendings of duplicates, under a special exchange arrangement, to the Musée Nationale d'Histoire Naturelle, Paris, the John Crerar Library, Chicago, the Marine Biological Laboratory, Woods Hole, and the libraries of the following colleges and universities: Brown, Catholic, Columbia, Hamilton, Harvard, Pennsylvania, Princeton, Vanderbilt, and Yale. From these institutions, as well as from Cornell University, Massachusetts Institute of Technology, and the American Academy of Arts and Sciences, were received many valuable publications, most of which, if it had not been for the special exchange arrangement referred to, the library would have had to buy.

Finally, the staff was called on for even more reference and bibliographical service than usual, not only in connection with the regular interests of the Institution in science, technology, and art, but in

response to inquiries of a miscellaneous character from correspondents throughout the country.

NEEDS

The needs of the library remain the same—more trained assistants, more funds for binding and for purchasing necessary books and periodicals that cannot be obtained in exchange, and more shelf room for several of the important collections that have outgrown their accommodations.

Respectfully submitted.

WILLIAM L. CORBIN, *Librarian.*

Dr. C. G. ABBOT,
  Secretary, Smithsonian Institution.

APPENDIX 10

REPORT ON PUBLICATIONS

Sir: I have the honor to submit the following report on the publications of the Smithsonian Institution and the Government branches under its administrative charge during the year ended June 30, 1936:

The Institution published during the year 29 papers in the series of Smithsonian Miscellaneous Collections, 1 annual report, and pamphlet copies of the 21 articles contained in the report appendix, and 3 special publications.

The United States National Museum issued 1 annual report, 11 Proceedings papers, and 1 number of the Contributions from the National Herbarium.

The Bureau of American Ethnology issued 1 annual report and 2 Bulletins.

Of the publications there were distributed 124,359 copies, which included 75 volumes and separates of the Smithsonian Contributions to Knowledge, 56,495 volumes and separates of the Smithsonian Miscellaneous Collections, 20,765 volumes and separates of the Smithsonian Annual Reports, 3,134 Smithsonian special publications, 33,936 volumes and separates of the National Museum publications, 9,337 publications of the Bureau of American Ethnology, 76 publications of the National Gallery of Art, 22 publications of the Freer Gallery of Art, 21 Annals of the Astrophysical Observatory, 20 reports of the Harriman Alaska Expedition, and 478 reports of the American Historical Association.

SMITHSONIAN MISCELLANEOUS COLLECTIONS

Of the Smithsonian Miscellaneous Collections, volume 91, there were issued 4 papers; volume 93, 1 paper; volume 94, 12 papers and title page and table of contents; and volume 95, 12 papers, making 29 papers in all, as follows:

VOLUME 91

Reports on the collections obtained by the first Johnson-Smithsonian Deep-Sea Expedition to the Puerto Rican Deep.

No. 21. Fourteen new species of foraminifera, by Joseph A. Cushman. 9 pp., 3 pls. (Publ. 3327.) July 23, 1935.

No. 22. Two new foraminifera of the genus *Textularia*, by Cecil G. Lalicker. 2 pp., 1 pl. (Publ. 3328.) July 22, 1935.

No. 23. A new genus of opisthognathid fishes, by George S. Myers. **5 pp., 1** text fig. (Publ. 3347.)   December 24, 1935.

No. 24. Four new brittlestars from Puerto Rico, by Austin H. Clark. 8 pp., 3 pls. (Publ. 3378.)   February 8, 1936.

VOLUME 93

No. 10. An introduction to Nebraska archeology, by William Duncan Strong. 315 pp., 25 pls., 30 figs. (Publ. 3303.)   July 20, 1935.

Title page and table of contents. (Publ. 3340.)

VOLUME 94

No. 6. The abdominal mechanisms of a grasshopper, by R. E. Snodgrass. 89 pp., 41 figs. (Publ. 3335.)   September 25, 1935.

No. 7. A new and important copepod habitat, by Charles Branch Wilson. 13 pp., 8 figs. (Publ. 3336.)   September 20, 1935.

No. 8. The Manahoac tribes in Virginia, 1608, by David I. Bushnell, Jr. 56 pp., 21 pls., 11 figs. (Publ. 3337.)   October 9, 1935.

No. 9. Review of the genus *Chlaenobia* Blanchard (Coleoptera : Scarabaeidae), by Edward A. Chapin. 20 pp., 12 figs. (Publ. 3338.)   September 23, 1935.

No. 10. Solar radiation and weather studies, by C. G. Abbot. 89 pp., 3 pls., 38 figs. (Publ. 3339.)   August 15, 1935.

No. 11. Melanesians and Australians and the peopling of America, by Aleš Hrdlička. 58 pp. (Publ. 3341.)   October 18, 1935.

No. 12. Mount St. Katherine, an excellent solar-radiation station, by C. G. Abbot. 11 pp., 2 pls., 1 fig. (Publ. 3342.)   October 5, 1935.

No. 13. Morphology of the coleopterous family Staphylinidae, by Richard E. Blackwelder. 102 pp., 30 figs. (Publ. 3343.)   March 2, 1936.

No. 14. A Caddo burial site at Natchitoches, Louisiana, by Winslow M. Walker. 15 pp., 6 pls., 3 figs. (Publ. 3345.)   December 17, 1935.

No. 15. Aerial fertilization of wheat plants with carbon-dioxide gas, by Earl S. Johnston. 9 pp., 6 pls. (Publ. 3346.)   December 20, 1935.

No. 16. The genus *Panscopus* Schoenherr (Coleoptera : Curculionidae), by L. L. Buchanan. 18 pp., 2 figs. (Publ. 3376.)   February 6, 1936.

No. 17. Growth of a green alga in isolated wave-length regions, by Florence E. Meier. 12 pp., 1 pl., 1 fig. (Publ. 3377.)   February 21, 1936.

Title page and table of contents. (Publ. 3387.)

VOLUME 95

No. 1. Observing the sun at 19,300 feet altitude, Mount Aunconquilcha, Chile, by C. P. Butler. 4 pp., 1 fig. (Publ. 3379.)   February 18, 1936.

No. 2. Lethal effect of short wave lengths of the ultraviolet on the alga *Chlorella vulgaris*, by Florence E. Meier. 19 pp., 2 pls., 2 figs. (Publ. 3380.) March 20, 1936.

No. 3. Liquid-propellant rocket development, by Robert H. Goddard. 10 pp., 11 pls., 1 fig. (Publ. 3381.)   March 16, 1936.

No. 4. Second contribution to nomenclature of Cambrian trilobites, by Charles Elmer Resser. 29 pp. (Publ. 3383.)   April 1, 1936.

No. 5. Molluscan intermediate hosts of the Asiatic blood fluke, *Schistosoma japonicum*, and species confused with them, by Paul Bartsch. 60 pp., 8 pls. (Publ. 3384.)   May 11, 1936.

No. 6. New species of American Edrioasteroidea, by R. S. Bassler. 33 pp., 7 pls. (Publ. 3385.)   May 4, 1936.

No. 7. The gold-banded skipper (*Rhabdoides cellus*), by Austin H. Clark. 50 pp., 8 pls., 4 figs. (Publ. 3386.) May 6, 1936.

No. 8. Thomas Walter, botanist, by William R. Maxon. 6 pp. (Publ. 3388.) April 22, 1936.

No. 9. Preliminary observations on growth and phototropic response of oat seedlings, by Enoch Karrer. 4 pp., 1 fig. (Publ. 3389.) June 2, 1936.

No. 10. Additional information on the Folsom complex: Report on the second season's investigations at the Lindenmeier site in northern Colorado, by Frank H. H. Roberts, Jr. 38 pp., 12 pls., 5 figs. (Publ. 3390.) June 20, 1936.

No. 11. Influence of planetary configurations upon the frequency of visible sun spots, by Fernando Sanford. 5 pp. (Publ. 3391.) June 5, 1936.

No. 12. The dependence of terrestrial temperatures on the variations of the sun's radiation, by C. G. Abbot. 15 pp., 7 figs. (Publ. 3392.) May 23, 1936.

SMITHSONIAN ANNUAL REPORTS

Report for 1934.—The complete volume of the Annual Report of the Board of Regents for 1934 was received from the Public Printer in October 1935.

Annual Report of the Board of Regents of the Smithsonian Institution showing operations, expenditures, and condition of the Institution for the year ending June 30, 1934. xiv+448 pp., 73 pls., 45 text figs. (Publ. 3305.)

The appendix contained the following papers:

The new world-picture of modern physics, by Sir James H. Jeans.

The markings and rotation of Mercury, by E. M. Antoniadi.

British Polar Year Expedition to Fort Rae, Northwest Canada, 1932–33, by J. M. Stagg.

Protium-deuterium-tritium, the hydrogen trio, by Hugh S. Taylor.

Some chemical aspects of life, by Sir Frederick Gowland Hopkins.

Commercial extraction of bromine from sea water, by Leroy C. Stewart.

Before papyrus—beyond rayon, by Gustavus J. Esselen.

The variety in tides, by H. A. Marmer.

Modern seismology, by F. J. Scrase.

A generation's progress in the study of evolution, by Edwin G. Conklin.

How the fishes learned to swim, by Anatol Heintz.

Curious and beautiful birds of Ceylon, by Casey A. Wood.

The influence of civilzation on the insect fauna in cultivated areas of North America, by Roger C. Smith.

Arctic butterflies, by Austin H. Clark.

Grasses, what they are and where they live, by A. S. Hitchcock.

Phototropism: A specific growth response to light, by Earl S. Johnston.

An outline development of highway travel, espeually in America, by Carl W. Mitman.

Via Appia in the days when all roads led to Rome, by Albert C. Rose.

Smithsonian archeological projects conducted under the Federal Emergency Relief Administration, 1933–34, by M. W. Stirling.

Indian cultures of northeastern South America, by Herbert W. Krieger.

Commerce, trade, and monetary units of the Maya, by Frans Blom.

Report for 1935.—The report of the Secretary, which included the financial report of the executive committee of the Board of Regents,

and will form part of the annual report of the Board of Regents to Congress, was issued in January 1936.

Report of the Secretary of the Smithsonian Institution and financial report of the executive committee of the Board of Regents for the year ending June 30, 1935. 90 pp., 2 pls. (Publ. 3344.)

The report volume, containing the general appendix, was in press at the close of the year.

SPECIAL PUBLICATIONS

Biographical sketch of James Smithson. 17 pp., 4 pls. (Reprint.) 1936.

Explorations and field work of the Smithsonian Institution in 1935. 80 pp., 85 figs. (Publ. 3382.) April 20, 1936.

Illustrations of North American pitcherplants, by Mary Vaux Walcott. Descriptions and notes on distribution, by Edgar T. Wherry. Notes on insect associates, by Frank Morton Jones. 4°. 34 pp., 15 color pls., 10 figs. October 1935.

PUBLICATIONS OF THE UNITED STATES NATIONAL MUSEUM

The editorial work of the National Museum has continued during the year under the immediate direction of the editor, Paul H. Oehser. There were issued 1 annual report, 11 separates from the Proceedings, and one number from the Contributions from the National Herbarium, as follows:

MUSEUM REPORT

Report on the progress and condition of the United States National Museum for the year ended June 30, 1935. 8vo, iii+121 pp. January.

CONTRIBUTIONS FROM THE NATIONAL HERBARIUM: VOLUME 26

Part 8. New species of *Pilea* from the Andes. By E. P. Killip. Pp. i–viii, 367–394. January 30, 1936.

PROCEEDINGS: VOLUME 83

No. 2979. New West Indian cerambycid beetles. By W. S. Fisher. Pp. 189–210. September 9, 1935.

No. 2980. Two new species of tapeworms from carnivores and a redescription of *Taenia laticollis* Rudolphi, 1819. By Mary Scott Skinker. Pp. 211–220, pls. 19–21. October 25, 1935.

No. 2981. Paleocene mammals from the Fort Union of Montana. By George Gaylord Simpson. Pp. 221–244. October 18, 1935.

No. 2982. Five new genera and two new species of unstalked crinoids. By A. H. Clark. Pp. 245–250. March 14, 1936.

No. 2983. Notes on the butterflies of the genus *Enodia* and description of a new fritillary from Peru. By A. H. Clark. Pp. 251–259, pl. 22. April 11, 1936.

No. 2984. Polychaetous annelids from Amoy, China. By Aaron L. Treadwell. Pp. 261–279, figs. 18–20. June 10, 1936.

No. 2985. A study of the fossil horse remains from the Upper Pliocene of Idaho. By C. Lewis Gazin. Pp. 281–320, figs. 21–24, pls. 23–33. June 1, 1936.

No. 2986. A new genus and species of trematodes from the little brown bat

and a key to the genera of Pleurogenetinae. By Ralph W. Macy. Pp. 321–324, fig. 25. May 19, 1936.

No. 2987. Two new cottid fishes from the western Pacific, with a revision of the genus *Stlengis* Jordan and Starks. By Rolf L. Bolin. Pp. 325–334, figs. 26–27, pl. 34. June 15, 1936.

No. 2988. Tertiary plants from Venezuela. By Edward W. Berry. Pp. 335–360, figs. 28–31. June 12, 1936.

No. 2989. Three new millipeds of the order Colobognatha from Tennessee, Texas, and Lower California, with records of previously known species. By H. F. Loomis. Pp. 361–368, fig. 32. May 11, 1936.

PUBLICATIONS OF THE BUREAU OF AMERICAN ETHNOLOGY

The editorial work of the bureau has continued under the immediate direction of the editor, Stanley Searles. During the year one annual report and two bulletins were issued, as follows:

Fifty-second Annual Report on the Bureau of American Ethnology to the Secretary of the Smithsonian Institution, 1934–1935. 8 pp.

Bulletin 112. An introduction to Pawnee archeology. By Waldo Rudolph Wedel. 122 pp., 12 pls., 10 maps, 12 figs.

Bulletin 113. The Troyville mounds, Catahoula Parish, La. By Winslow M. Walker. 73 pp., 16 pls., 15 figs.

REPORT OF THE AMERICAN HISTORICAL ASSOCIATION

The annual reports of the American Historical Association are transmitted by the association to the Secretary of the Smithsonian Institution and are communicated by him to Congress, as provided by the act of incorporation of the association.

Volume II of the report for 1931, Writings in American History, 1931, was issued during the year. The annual report for 1935, including the proceedings of the association for 1933 and 1934, and the supplemental volumes to the reports for 1932 and 1933, Writings in American History, 1932 and 1933, were in press at the close of the year.

REPORT OF THE NATIONAL SOCIETY, DAUGHTERS OF THE AMERICAN REVOLUTION

The manuscript of the Thirty-eighth Annual Report of the National Society, Daughters of the American Revolution, was transmitted to Congress, in accordance with law, December 10, 1935.

ALLOTMENTS FOR PRINTING

The congressional allotments for the printing of the Smithsonian Annual Reports to Congress and the various publications of the Government bureaus under the administration of the Institution were virtually used up at the close of the year. The appropriation

for the coming year ending June 30, 1937, totals $55,500, allotted as follows:

Smithsonian Institution	$12,400
National Museum	25,000
Bureau of American Ethnology	9,000
International Exchange Service	200
National Zoological Park	200
Astrophysical Observatory	400
American Historical Association	8,000
National Gallery of Art	300

In addition to these amounts, an appropriation of $12,000 for printing and binding was included in the Urgent Deficiency Bill. This will be used for urgent binding.

Respectfully submitted.

W. P. True, *Editor.*

Dr. C. G. Abbot,
  Secretary, Smithsonian Institution.

REPORT OF THE EXECUTIVE COMMITTEE OF THE BOARD OF REGENTS OF THE SMITHSONIAN INSTITUTION

FOR THE YEAR ENDED JUNE 30, 1936

To the Board of Regents of the Smithsonian Institution:

Your executive committee respectfully submits the following report in relation to the funds of the Smithsonian Institution, together with a statement of the appropriations by Congress for the Government bureaus in the administrative charge of the Institution.

SMITHSONIAN ENDOWMENT FUND

The original bequest of James Smithson was £104,960 8s. 6d.—$508,318.46. Refunds of money expended in prosecution of the claim, freights, insurance, etc., together with payment into the fund of the sum of £5,015, which had been withheld during the lifetime of Madame de la Batut, brought the fund to the amount of _____ $550,000.00

Since the original bequest the Institution has received gifts from various sources, chiefly in the years prior to 1893, the income from which may be used for the general work of the Institution.

To these gifts has been added capital from savings on income, gain from sale of securities, etc., bringing the total endowment for general purposes to the amount of _____ 1,117,419.22

The Institution holds also a number of endowment gifts, the income of each being restricted to specific use. These are invested and stand on the books of the Institution as follows:

Arthur, James, fund, income for investigations and study of sun and lecture on the sun _____ $40,606.64

Bacon, Virginia Purdy, fund, for a traveling scholarship to investigate fauna of countries other than the United States _____ 50,869.12

Baird, Lucy H., fund, for creating a memorial to Secretary Baird ____ 9,207.86

Barstow, Frederic D., fund, for purchase of animals for the Zoological Park _____ 772.34

Canfield Collection fund, for increase and care of the Canfield collection of minerals _____ 38,833.61

Casey, Thomas L., fund, for maintenance of the Casey collection and promotion of researches relating to Coleoptera _____ 7,846.82

Chamberlain, Francis Lea, fund, for increase and promotion of Isaac Lea collection of gems and mollusks _____ 28,592.33

Hillyer, Virgil, fund, for increase and care of Virgil Hillyer collection of lighting objects _____ 6,673.02

Hodgkins fund, specific, for increase and diffusion of more exact knowledge in regard to nature and properties of atmospheric air__ 100,000.00

Special Research fund, gift, in form of real estate_____ $20, 946. 00

Hughes, Bruce, fund, to found Hughes alcove_____ 15, 382. 40

Myer, Catherine Walden, fund, for purchase of first-class works of
    art for the use of and benefit of the National Gallery of Art_____ 19, 246. 73

Pell, Cornelia Livingston, fund, for maintenance of Alfred Duane
    Pell collection_____ 2, 450. 56

Poore, Lucy T. and George W., fund, for general use of the Institu-
    tion when principal amounts to the sum of $250,000_____ 66, 201. 14

Reid, Addison T., fund, for founding chair in biology in memory of
    Asher Tunis_____ 29, 293. 14

Roebling fund, for care, improvement, and increase of Roebling col-
    lection of minerals_____ 122, 533. 38

Rollins, Miriam and William, fund, for investigations in physics
    and chemistry_____ 53, 568. 12

Springer, Frank, fund, for care, etc., of Springer collection and
    library_____ 18, 207. 84

Walcott, Charles D., and Mary Vaux, research fund, for develop-
    ment of geological and paleontological studies and publishing
    results thereof_____ 10, 718. 44

Younger, Helen Walcott, fund, held in trust_____ 50, 112. 50

Zerbee, Frances Brincklé, fund, for endowment of aquaria_____ 772. 75

      Total endowment for specific purposes other than Freer
        endowment_____ 692, 834. 74

The capital funds of the Institution, except the Freer funds, are invested as follows:

Fund	United States Treasury	Consoli- dated fund	Separate fund	Total
Arthur, James	----------	$40, 606. 64	----------	$40, 606. 64
Bacon, Virginia Purdy	----------	50, 869. 12	----------	50, 869. 12
Baird, Lucy H	----------	9, 207. 86	----------	9, 207. 86
Barstow, Frederic D	----------	772. 34	----------	772. 34
Canfield Collection	----------	38, 833. 61	----------	38, 833. 61
Casey, Thomas L	----------	7, 846. 82	----------	7, 846. 82
Chamberlain	----------	28, 592. 33	----------	28, 592. 33
Hillyer, Virgil	----------	6, 673. 02	----------	6, 673. 02
Hodgkins, specific	$100, 000	----------	----------	100, 000. 00
Special Research	----------	----------	$20,946.00	20, 946. 00
Hughes, Bruce	----------	15, 382. 40	----------	15, 382. 40
Myer, Catherine W	----------	19, 246. 73	----------	19, 246. 73
Pell, Cornelia Livingston	----------	2, 450. 56	----------	2, 450. 56
Poore, Lucy T. and George W	26, 670	39, 531. 14	----------	66, 201. 14
Reid, Addison T	11, 000	13, 793. 14	4, 500. 00	29, 293. 14
Roebling Collection	----------	122, 533. 38	----------	122, 533. 38
Rollins, Miriam and William	----------	44, 068. 12	9, 500. 00	53, 568. 12
Smithsonian unrestricted:				
Special	----------	----------	1, 400. 00	1, 400. 00
Avery	14, 000	37, 807. 71	----------	51, 807. 71
Endowment	----------	177, 090. 38	----------	177, 090. 38
Habel	500	----------	----------	500. 00
Hachenberg	----------	4, 083. 16	----------	4, 083. 16
Hamilton	2, 500	409. 87	----------	2, 909. 87
Henry	----------	1, 227. 97	----------	1, 227. 97
Hodgkins (general)	116, 000	30, 446. 49	----------	146, 446. 49
Parent	727, 640	1, 239. 50	----------	728, 879. 50
Rhees	590	480. 33	----------	1, 070. 33
Sanford	1, 100	903. 81	----------	2, 003. 81
Springer	----------	18, 207. 84	----------	18, 207. 84
Walcott, Charles D. and Mary Vaux	----------	10, 718. 44	----------	10, 718. 44
Younger, Helen Walcott	----------	----------	50, 112. 50	50, 112. 50
Zerbee, Frances Brincklé	----------	772. 75	----------	772. 75
Total	1, 000, 000	723, 795. 46	86, 458. 50	1, 810, 253. 96

FREER GALLERY OF ART FUND

Early in 1906, by deed of gift, Charles L. Freer, of Detroit, gave to the Institution his collection of Chinese and other oriental objects of art, as well as paintings, etchings, and other works of art by Whistler, Thayer, Dewing, and other artists. Later he also gave funds for the construction of a building to house the collection, and finally, in his will, probated November 6, 1919, he provided stock and securities to the estimated value of $1,958,591.42 as an endowment fund for the operation of the gallery. From the above date to the present time these funds have been increased by stock dividends, savings of income, etc., to a total of $4,651,867.07. In view of the importance and special nature of the gift and the requirements of the testator in respect to it, all Freer funds are kept separate from the other funds of the Institution, and the accounting in respect to them is stated separately.

The invested funds of the Freer bequest are classified as follows:

Court and grounds fund	$521,158.68
Court and grounds maintenance fund	131,062.81
Curator fund	530,333.92
Residuary legacy	3,469,311.66
	4,651,867.07

SUMMARY

Invested endowment for general purposes	$1,117,419.22
Invested endowment for specific purposes other than Freer endowment	692,834.74
Total invested endowment other than Freer endowment	1,810,253.96
Freer invested endowment for specific purposes	4,651,867.07
Total invested endowment for all purposes	6,462,121.03

CLASSIFICATION OF INVESTMENTS

Deposited in the U. S. Treasury at 6 percent per annum, as authorized in the U. S. Revised Statutes, sec. 5591		$1,000,000.00
Investments other than Freer endowment (cost or market value at date acquired):		
Bonds (20 different groups)	$334,888.21	
Stocks (55 different groups)	428,954.79	
Real estate and first-mortgage notes	41,746.00	
Uninvested capital	4,664.96	
		810,253.96
Total investments other than Freer endowment		1,810,253.96

Investments of Freer endowment (cost or market
  value at date acquired) :

Bonds (42 different groups)	$2, 153, 477. 00	
Stocks (50 different groups)	2, 458, 494. 73	
Real estate first-mortgage notes	37, 500. 00	
Uninvested capital	2, 395. 34	
		$4, 651, 867. 07

Total investments _____ 6, 462, 121. 03

CASH BALANCES, RECEIPTS, AND DISBURSEMENTS DURING THEE FISCAL YEAR [1]

Cash balance on hand June 30, 1935_____ $578, 572. 12

Receipts:

Cash income from various sources for general
  work of the Institution _____ $66, 611. 05

Cash gifts and contributions expendable for spe-
  cial scientific objects (not to be invested) _____ 23, 998. 62

Cash gifts for special scientific work (to be in-
  vested) _____ 7, 000. 00

Cash income from endowments for specific use
  other than Freer endowment and from miscel-
  laneous sources (including refund of temporary
  advances) _____ 60, 089. 96

Cash received as royalties from Smithsonian
  Scientific Series_____ 37, 875. 92

Cash capital from sale, call of securities, etc. (to
  be reinvested)_____ 151, 534. 99

Total receipts other than Freer endowment_____ 347, 110. 54

Cash receipts from Freer endowment: Income
  from investments, etc_____ 259, 420. 73

Cash capital from sale, call of securities, etc.
  (to be reinvested) _____ 1, 175, 874. 51

Total receipts from Freer endowment_____ 1, 435, 295. 24

Total _____ 2, 360, 977. 90

Disbursements:

From funds for general work of the Institution:

Buildings, care, repairs, and alterations	$3, 988. 87	
Furniture and fixtures	438. 79	
General administration [2]	27, 002. 60	
Library	2, 208. 85	
Publications (comprising preparation, print- ing, and distribution)	16, 555. 16	
Researches and explorations	17, 090. 34	
International Exchanges	4, 788. 30	
		72, 072. 91

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[1] This statement does not include Government appropriations under the administrative charge of the Institution.

[2] This includes salary of the Secretary and certain others.

Disbursements—Continued.

From funds for specific use, other than Freer endowment:

Investments made from gifts, from gain from sale, etc., of securities and from savings on income	$11, 608. 81	
Other expenditures, consisting largely of research work, travel, increase and care of special collections, etc., from income of endowment funds and from cash gifts for specific use (including temporary advances)	94, 450. 36	
Reinvestment of cash capital from sale, call of securities, etc	164, 432. 67	
		$270, 491. 84

From Freer endowment:

Operating expenses of the gallery, salaries, field expenses, etc	67, 882. 17	
Purchase of art objects	213, 876. 72	
Investments made from gain from sale, etc., of securities	75, 756. 14	
Reinvestment of cash capital from sale, call of securities, etc	1, 431, 373. 56	
Accrued interest on bonds purchased	7, 072. 13	
		1, 795, 960. 72
Cash balance June 30, 1936		222, 452. 43
Total		2, 360, 977. 90

EXPENDITURES FOR RESEARCHES IN PURE SCIENCE, PUBLICATIONS, EXPLORATIONS, CARE, INCREASE, AND STUDY OF COLLECTIONS, ETC.

Expenditures from general funds of the Institution:

Publications	$16, 555. 16	
Researches and explorations	17, 090. 34	
		$33, 645. 50

Expenditures from funds devoted to specific purposes:

Researches and explorations	57, 669. 45	
Care, increase, and study of special collections	12, 545. 96	
Publications	6, 033. 72	
		76, 249. 13
Total		109, 894. 63

The practice of depositing on time in local trust companies and banks such revenues as may be spared temporarily has been continued during the past year, and interest on these deposits has amounted to $925.30.

The Institution gratefully acknowledges gifts or bequests from the following:

Mrs. Laura Welsh Casey, for further contributions to Thomas Lincoln Casey fund, for investigations in Coleoptera.

Mrs. Virgil M. Hillyer, for the establishment of a fund the income from which is to be used in the care and increase of the Virgil Hillyer collection of lighting objects.

Research Corporation, for further contributions for researches in radiation.

Mrs. Mary Vaux Walcott, for contribution for the purchase of certain specimens and a collection of pamphlets on anthropology.

All payments are made by check, signed by the Secretary of the Institution on the Treasurer of the United States, and all revenues are deposited to the credit of the same account. In many instances deposits are placed in bank for convenience of collection and later are withdrawn in round amounts and deposited in the Treasury.

The foregoing report relates only to the private funds of the Institution.

The following annual appropriations were made by Congress for the Government bureaus under the administrative charge of the Smithsonian Institution for the fiscal year 1936:

Salaries and expenses		$36,326.00
International Exchanges		44,262.00
American Ethnology		58,730.00
Astrophysical Observatory		30,846.00
National Museum:		
Maintenance and operation	$125,672.00	
Preservation of collections	594,578.00	
		720,250.00
National Gallery of Art		34,275.00
Printing and binding		37,500.00
National Zoological Park		215,000.00
		1,177,189.00

Provision was made for participation by the Smithsonian Institution in the following expositions:

California Pacific International Exposition (unexpended balance of allotment made last year, made available until January 1, 1937)	$916.19
Texas Centennial Exposition	10,000.00
Great Lakes Exposition	700.00

An appropriation was also made providing $25,000 for the purchase of the airplane *Winnie Mae* and equipment used by Wiley Post in his world flight.

The report of the audit of the Smithsonian private funds is printed below:

AUGUST 28, 1936.

EXECUTIVE COMMITTEE, BOARD OF REGENTS,
Smithsonian Institution, Washington, D. C.

SIRS: Pursuant to agreement we have audited the accounts of the Smithsonian Institution for the fiscal year ended June 30, 1936, and certify the balance of cash on hand June 30, 1936, to be $224,352.43 (which includes $1,900 cash in safe).

We have verified the record of receipts and disbursements maintained by the Institution and the agreement of the book balances with the bank balances.

We have examined all the securities in the custody of the Institution and in the custody of the banks and found them to agree with the book records.

We have compared the stated income of such securities with the receipts of record and found them in agreement therewith.

We have examined all vouchers covering disbursements for account of the Institution during the fiscal year ended June 30, 1936, together with the authority therefor, and have compared them with the Institution's record of expenditures and found them to agree.

We have examined and verified the accounts of the Institution with each trust fund.

We found the books of account and records well and accurately kept and the securities conveniently filed and securely cared for.

All information requested by your auditors was promptly and courteously furnished.

We certify the balance sheet, in our opinion, correctly presents the financial condition of the Institution as at June 30, 1936.

Respectfully submitted.

WILLIAM L. YAEGER & CO.,
WILLIAM L. YAEGER,
Certified Public Accountant.

Respectfully submitted.

FREDERIC A. DELANO,
R. WALTON MOORE,
JOHN C. MERRIAM,
Executive Committee.

GENERAL APPENDIX

TO THE

SMITHSONIAN REPORT FOR 1936

ADVERTISEMENT

The object of the GENERAL APPENDIX to the Annual Report of the Smithsonian Institution is to furnish brief accounts of scientific discovery in particular directions; reports of investigations made by collaborators of the Institution; and memoirs of a general character or on special topics that are of interest or value to the numerous correspondents of the Institution.

It has been a prominent object of the Board of Regents of the Smithsonian Institution from a very early date to enrich the annual report required of them by law with memoirs illustrating the more remarkable and important developments in physical and biological discovery, as well as showing the general character of the operations of the Institution; and, during the greater part of its history, this purpose has been carried out largely by the publication of such papers as would possess an interest to all attracted by scientific progress.

In 1880, induced in part by the discontinuance of an annual summary of progress which for 30 years previously had been issued by well-known private publishing firms, the secretary had a series of abstracts prepared by competent collaborators, showing concisely the prominent features of recent scientific progress in astronomy, geology, meteorology, physics, chemistry, mineralogy, botany, zoology, and anthropology. This latter plan was continued, though not altogether satisfactorily, down to and including the year 1888.

In the report for 1889 a return was made to the earlier method of presenting a miscellaneous selection of papers (some of them original) embracing a considerable range of scientific investigation and discussion. This method has been continued in the present report for 1936.

ASTRONOMY IN SHAKESPEARE'S TIME
AND IN OURS

By C. G. ABBOT

Secretary, Smithsonian Institution

[With 6 plates]

About 50 years ago Dr. S. P. Langley, third secretary of the Smithsonian Institution, wrote a charming book called The New Astronomy. He pointed out that from the earliest times almost until his own, astronomy had been restricted to the study of the positions and motions of the heavenly bodies. Now the inquiry had become more and more: What are members of the heavenly host in chemical and physical constitution? Both branches of astronomy have made astonishing progress since Langley wrote, as we shall see in contrasting astronomy's present status with that of Shakespeare's time. What I wish to emphasize by referring to Langley's book is that nothing that depends on the use of the spectroscope or of photography was known to the astronomers of Galileo's and Shakespeare's generation. And we may well estimate that three-fourths of our present knowledge of the subject depends on photographic and spectroscopic observations.

Astronomy is the distinguished child of that gypsylike mother, astrology. In Babylonia, the sun, moon, and planets were gods and goddesses. Fortunate and unfortunate public events were naturally associated with the intervention of the gods, and hence with the aspect of the heavenly bodies. It therefore became a priestly duty to watch the heavens for portents. In this way astrology was born, flourished, and gave birth to astronomy. During at least 2,000 years there grew up a great body of knowledge of the motions of the sun, moon, planets, and stars, but until the seventeenth century of our era there were no telescopes or accurate clocks by which observations exact enough to prove sound theory could be made.

The poet Shakespeare lived at the very beginning of a new astronomical epoch, which we may call the first age of the telescope, lasting through the sixteenth, seventeenth, and eighteenth centuries. Copernicus, indeed, had published his great work on the motions of
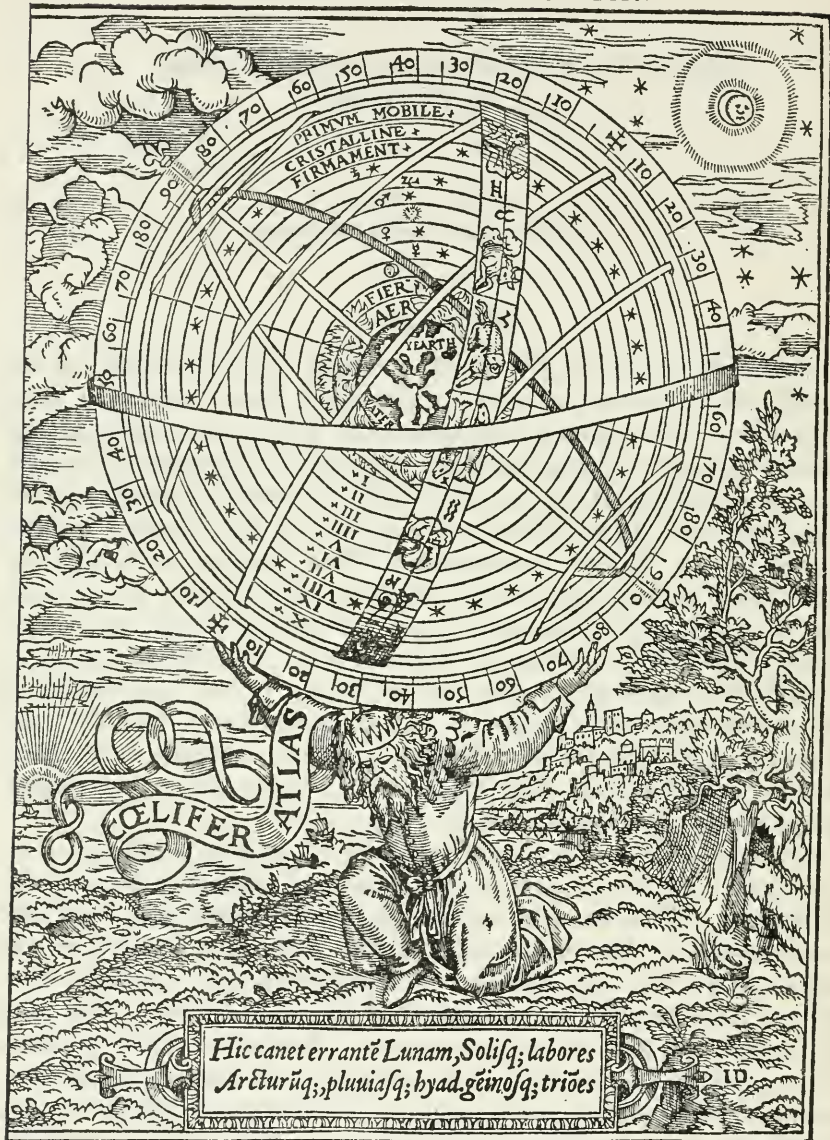
FIGURE 1.—Representation of the Ptolemaic system taken from "The Cosmographical Glasse, conteinyng the pleasant Principles of Cosmographie, Geographie, Hydrographie, or Navigation", by William Cuningham, London, 1559.

the heavenly bodies.   Kepler and Galileo, who made such notable dis-
coveries, were Shakespeare's contemporaries.   The telescope was
invented during his lifetime, and exact mechanisms were no longer
rare.   But printing was still costly, and intelligence traveled slowly.
Indeed, the work of these great astronomers just named was slow in
receiving recognition.   I believe there is no evidence from Shakes-
peare's writings that he was aware of them or of the results of their
investigations.   Like practically all other outstanding men of his
time, he appears to have accepted the system of Ptolemy, wherein
the earth was regarded as the center of the universe.   Though that
master introduced his numerous epicycles and equants merely as
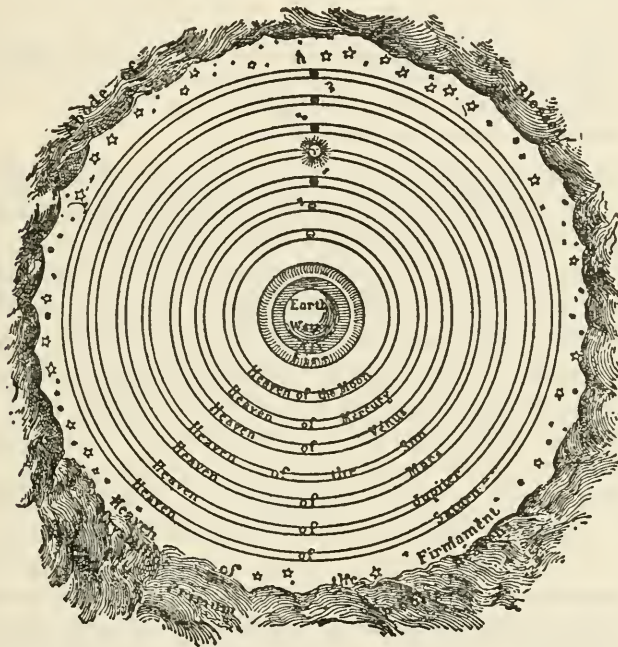
FIGURE 2.—Diagram of the Ptolemaic system.   The four substances, earth, water, air, fire,
which the ancients supposed to be world elements, are at the center.   (From The Uni-
verse, from Crystal Spheres to Relativity, by Frank Allen.   Harcourt, Brace & Co., New
York, 1931.)

mathematical devices, the vulgar understanding of his system con-
ceived it to imply that the moon, the sun, the planets, and the stars
were affixed to spheres of greater and greater remoteness from the
earth.   These spheres, it was supposed, moved according to combina-
tions or circular guidances too complicated for description here.   It
was the concert of these spheres which made heavenly harmony ac-
cording to Pythagoras.   Beyond the farthest sphere, to which the
stars were fixed, lay Heaven itself, the homeland of the blest.

The good sense of Shakespeare rejected the extravagant claims of astrology, the mother of astronomy. In one of his sonnets he remarks:

> Not from the stars do I my judgment pluck;
> And yet methinks I have astronomy,
> But not to tell of good or evil luck,
> Of plagues, of dearths, or seasons' quality.

<div align="right">(From XIVth Sonnet.)</div>

Indeed he had astronomy! From the earliest times the celestial host has always been an inspiration to literature. The Psalmist sings:

> The Heavens declare the glory of God
> And the Firmament showeth his handiwork.

Again:

> When I consider Thy Heavens, the work of Thy fingers
> The moon and the stars which Thou has ordained
> What is man that Thou art mindful of him
> Or the son of man that Thou visitest him.

Yet compared to the glorious blaze of knowledge of these subjects in which we now live, the astronomical reflections which the Psalmist or even Shakespeare could indulge were as the faintest glimmering. From the astonishing combination of simplicity and complexity residing in the submicroscopic atomic world to the infinitely outreaching boundaries of the starry universe as we now know them, there is displayed such a wealth of marvelous adaptations as cannot fail to inspire even the dullest person with astonishment and awe.

Consider any solid body; be it stone, wood, metal, flesh, or any other. Imagine a single morsel of it, no larger than a mote that flies in the sunbeam. Small as it is, it contains at least 10 million billion molecules. Each of these molecules contains many atoms. Each of these atoms contains several or many smaller bodies besides protons and electrons. But these multitudinous ultimate constituents of every speck of matter lie so far separated one from another that they are relatively as remote, each to each, as the stars are in the heavens. Solids, then, are no more to be regarded as solids, but rather as openwork, gossamerlike constructions, wherein the spaces are immense compared to the occupied parts. Motions of the most beautiful configurations dance about within these systems. The electric forces which are imprisoned in these infinitesimal structures baffle imagination to conceive of their immensity. A large book would not suffice to tell of all the wonders that one invisible atom contains, in a space far below the limit of vision of the most powerful microscope.

On the other hand, consider the heavens. We live upon the earth, 8,000 miles in diameter, which revolves about the sun 93,000,000

miles away, and more than 300,000 times as massive as the earth. Our sun is one of the many billions of suns which we call the stars, some of them a billion times as large as it, which throng the Milky Way. The very nearest of them to our sun is α Centauri, a bright star of the Southern Hemisphere. It lies so far away that light itself, traveling 186,000 miles each second, requires 4 years to reach us. From the remotest stars of our galaxy, light requires 100,000 years to come. But this is by no means the limit of the universe. It may even be limitless. At least we know that on every side of our own starry host lie other galaxies. They are certainly millions in number. Each of them contains, like ours, a multitude of stars. These "island universes", as Herschel called them, lie a million light years apart, and we recognize them still at such immense distances that the light by which we photograph them today started toward us 200,000,000 years ago in Cambrian geologic times when our earth was in the possession of the trilobites extinct these hundred million years.

How keenly we must regret that the fertile mind of Shakespeare could not draw from this abounding store of wonders material about which to wield his magic wand of expression. In his time, atoms were practically unthought of, and for no star, not even for our sun, was there known the distance, motion, size, temperature, or physical or chemical composition. The universal unity of the building material of all nature, the vast reaches of the universe, and the astonishing numbers and immensity of its denizens could not possibly be imagined in their grand proportions which now we know.

As already remarked, Shakespeare was no astrologist. In King Lear, he puts derision of astrology into the mouth of Edmund, as follows:

When we are sick in fortune * * * we make guilty of our disasters the sun, the moon, and the stars, as if we were villains on necessity, fools by heavenly compulsion, knaves, thieves, and treachers by spherical predomi- nance, drunkards, liars, and adulterers, by enforc'd obedience of planetary influence, and all that we are evil in, by divine thrusting on.

Of course in his fidelity to actuality Shakespeare does not hesi- tate to put into the mouths of some of his characters exactly those beliefs in the good and evil influences of the heavenly bodies, and of obscure earthly things which were current among nearly all men of his time. For instance, Horatio, moved by the appearance of the ghost, refers as follows to the death of Caesar:

A little ere the mightiest Julius fell,
The graves stood tenantless and the sheeted dead
Did squeak and gibber in the Roman streets.

He continues, after a line now lost which might have read, "The heavens also with dread portents teemed":

> As stars with trains of fire and dews of blood,
> Disasters in the sun, and the moist star,
> Upon whose influence Neptune's empire stands
> Was sick almost to doomsday with eclipse.
> And even the like precurse of fierce events,
> As harbingers preceding still the fates
> And prologue to the omen coming on,
> Have heaven and earth together demonstrated
> Unto our climatures and countrymen.

In many other passages, Shakespeare distills the quintescence of beauty from old astronomical beliefs which now are obsolete. None of these references is more beautiful than those relating to Pythagoras' music of the spheres. One is found in the Merchant of Venice where Lorenzo says:

> How sweet the moonlight sleeps upon this bank;
> Here will we sit and let the sounds of music
> Creep in our ears. Soft stillness and the night
> Become the touches of sweet harmony.
> Sit, Jessica. Look how the floor of heaven
> Is thick inlaid with patines of bright gold.
> There's not the smallest orb which thou behold'st,
> But in his motion like an angel sings,
> Still quiring to the young-ey'd cherubins;
> Such harmony is in immortal souls;
> But while this muddy vesture of decay
> Doth grossly close it in, we cannot hear it.

In order to appreciate more truly the status of astronomy in Shakespeare's time, let us take a general bird's-eye view of the advance of that science up to the present.

The progress of astronomy suggests four epochs. In the first epoch the observer's eye was unaided by optical apparatus, accurate clocks were unavailable, communication of results was slow and costly, and records could only be multiplied by hand copying. The human intellect, though doubtless quite as keen then as now, had but rough and feeble observations to work upon. Hence, from the lack of observational groundwork the theory of astronomy was encumbered until a few centuries ago with a maze of spheres, cycles, and epicycles, and the pseudo-science of astrology stood on an equal or superior plane with true astronomy in public estimation. This first astronomical epoch began as the outgrowth of astrology in the dim past, and only merged into the second or epoch of the telescope, during the fifteenth and sixteenth centuries of our era. Among its greatest names stand Euclid, Archimedes, Hipparchus, Ptolemy, and Regiomontanus.

The second epoch was ushered in by the theory of Copernicus. By the invention of the telescope and the mechanical clock, great physical aids became available for observation. Printing, that greatest agency of human culture, had been invented. Mathematics, which in the first epoch grew to comprise arithmetic, algebra, geometry, and trigonometry, received in the second epoch not only the introduction of logarithms but the superpowerful reinforcement of the calculus which was invented by those great geniuses, Sir Isaac Newton and Leibnitz. Besides these great names already mentioned, Tycho Brahe, Kepler, Galileo, La Place, Bradley, the Herschels, and many others of nearly equal fame immortalize this epoch. The laws of Kepler, interpreted by Sir Isaac Newton in his theory of gravitation, were outstanding triumphs of theory. Bradley, with his discovery of aberration of light and his catalogs of star places, was the apostle of an accuracy almost modern.

At the beginning of the third epoch, about 1810 to 1840, stand four invaluable discoveries and one revolutionary observation. Photography, the spectroscope, the wave character of light, and improved optical glasses were the four discoveries, and the first measurement of the immense distance of one of the nearest stars by Bessel was the revolutionary observation. Bessel's measurement in 1837 gave an unimpeachable standing to the system of Copernicus. Prior to that time, everyone who accepted the view of Copernicus, that the earth revolves about the sun, had to accept on faith the proposition that all the stars are so immensely distant that they are shifted only imperceptibly in apparent position by the displacement of the earth in its revolution round the sun through nearly 200,000,000 miles each 6 months. Bessel measured such a shift. It corresponded to a star distance of 60 trillion miles. How astonishing must have seemed this tremendous extension of the universe to those to whom this immense distance first stood undeniably revealed! The improvements in optical glass led in this epoch to the construction of large achromatic refracting telescopes of short enough focus to be manageable. The older telescopes had required an excessive focal ratio to avoid spherical aberrations and were terribly unwieldy. Thus great power was added to eye observations. The diffraction grating for spectroscopic work was perfected by Ångström and Rowland. Photography, however, was delayed in coming to its own for astronomical use until near the beginning of the fourth astronomical epoch in which we now live. Spectrum analysis disclosed the chemistry of the sun and stars at the middle of the nineteenth century. Here again was something almost incredible: That we should ever know the composition of bodies trillions of miles away!

In the present or fourth epoch of astronomical progress, extraordinary aids to observation have come. These include the application to telescopes of great engineering construction and highly accurate mechanisms, fully equipped with electrical devices for their operation. The photographic plate, the thermionic amplifier, and the sensitive thermoelectric element have nearly displaced the eye at the observing end of the gigantic reflecting telescopes of the present day. Photographic records in which light builds up its story through many hours or even many nights may now be studied at leisure in the comfort of an office, instead of glimpsed in an instant at the eyepiece of a telescope in frigid winter midnight. Observations with powerful spectroscopes reveal the composition, motions, distances, and temperatures of the stars. Based on the science of thermodynamics, twentieth-century physical knowledge and studies of the mysteries of radium and radioactivity, of the inner construction of atoms, and of the effects of powerful excitations of atoms by electricity or heat, have settled questions of the natures of stars that formerly seemed insoluble. Such studies have even disclosed stars whose material is many times as dense as gold or platinum. And yet more paradoxical, such stars as these are nevertheless in the gaseous state! On the other extreme are disclosed stars several hundred million miles in diameter whose density is thousands of times less than that of air. Sir William Herschel's happy guess that the nebulae are other galaxies outside our own system, or, as he called them, "island universes", has proved to be correct. Millions of these remote galaxies have been disclosed, each like our own Milky Way containing multitudes of stars, but situated so enormously remotely that their light, traveling nearly 200,000 miles each second, requires many millions of years to come from them to us. We see them, therefore, as they were in former epochs of the earth's geology, when gigantic creatures now extinct abounded. What food would this have been to an imagination like our Shakespeare's!

Turning from these inspiring views of modern astronomical knowledge, let us now explore more particularly some of the instruments, the theories, and the observations which comprised the astronomy as generally known in Shakespeare's time. As we have remarked, the unaided eye had neither telescope, photographic plate, nor sensitive radiometer to assist it. The positions of the heavenly bodies could only be observed by casting shadows or by looking through sights analagous to those of a sporting gun. These two types of naked visual observation are exemplified in the sundial and in the astrolabe.

Nevertheless, much information was gathered by the ancients merely from the shadow of the sun. This knowledge reached far beyond its well-known use in the sundial to indicate the time of day.

For instance, by observing the length of the shadow of a vertical rod on a horizontal floor, noon would be indicated each day as the instant of the day's shortest shadow. Soon a mark could be made to indicate the direction of the shadow at every noon, and this would be the line of north and south. Presently it would appear that the end of the shadow at noon marched southward from July to December and then returned. A diligent observer, watching this march of the end of the noon shadow for several seasons, would obtain a more and more accurate measure of the length of the year. As long ago as the times of the ancient Chaldeans and Egyptians the year was thus known to be about 365¼ days. If shadow observations were continued over centuries, as doubtless they were by priests as religious rites, the fraction approximately one-fourth could be determined to several decimals.

From the total length of the excursion of the shadow's end between June and December, compared to the height of the rod which cast it, the angular inclination of the ecliptic to the Equator was determined several centures before Christ as 23½°. Eratosthenes, about two centuries before Christ, went further. He observed that the sun at midday in Alexandria at the summer solstice stood $\frac{1}{50}$ of a circumference, or about 7° from the zenith, whereas at Syene, in Upper Egypt, the sun at the same time stood exactly overhead. From this he inferred that the distance from Alexandria to Syene was $\frac{1}{50}$ of the circumference of the earth. His observation agrees closely with the truth. Another use of the march of the end of the sun's shadow from north to south would discover the dates at which it stood exactly half accomplished. These dates, corresponding to the equinoxes, would reveal the inequalities of several days which we now attribute to the ellipticity of the earth's orbit round the sun. Latitudes were also readily determined by the ancients from the direction and length of the sun's shadow.

But enough! We will not follow the shadow farther but turn our attention to the astrolabe, the pearl of ancient instruments. Imagine, if you please, that your watch was expanded in diameter several fold, and that its chain ended in a loop large enough to hang on the thumb or finger instead of in a bar or hook. Assume the weight of the watch increased to 1 or 2 pounds, its glass and works removed. On the face, instead of hands, would be pivoted a bar carrying peephole sights at either end, by means of which the axis of the bar could be pointed at the sun, a star, or at some terrestrial object. Corresponding to the position of the hours, III and IX of the watch would be the horizon line. The angle between the sighting bar and the horizon line could be read off on the graduated circle. Sighting through such an instrument, held

suspended from the upstretched hand, and directed to any point of the compass, the observer could readily measure the angular difference of elevation of any two stars, mountains, or other objects by subtracting their respective angular distances above the horizon line.

In addition to these features, the astrolabe had a complex frame, called the spider, or rete, upon its face. This frame was filled with points representing the positions of important stars. There were, besides, a number of metal plates packed within the body of the instrument. The proper one to suit the observer's latitude could be selected and exposed next under the spider. On this plate were drawn families of curves used for various purposes. For instance, after measuring the altitude of the sun, a setting could be made whereby the time of day was given. This setting involved the constellations of the zodiac which appeared on a circle, also part of the face of the instrument. On the back of the astrolabe was drawn a system of cross-section lines so that from any setting of the pointers there could at once be graphically computed some desired mathematical result.

The astrolabe maintained itself as an instrument of astrology, astronomy, and navigation for nearly 2,000 years. It was displaced by the mariner's sextant, invented by John Hadley about 1731. So highly was the astrolabe appreciated that it is still spoken of with regret that so choice an instrument is not quite up to modern requirements of accuracy. It is interesting to note that the poet Chaucer wrote a treatise on the astrolabe and its uses.

Although both the sun dial and the astrolabe were used from antiquity to tell the time of day, neither they nor the clepsydra, or water clock, reached the precision needed for fundamental progress in the theory of astronomy. The positions of the stars are known when their distances north or south of the celestial equator, that is, their declinations, are determined, and in addition the times at which they cross the meridian, which fixes their right ascensions. Therefore, not only must the astrolabe, or its equivalent, be used to measure the culminating angular distance above the horizon of a star to fix its declination, but it is no less important to measure the exact time when the star makes its meridian transit. There was no instrument in the hands of the ancients which could keep accurate time for 24 hours. An imperfect substitute for a true clock available to the old astronomers would be to note the relative lengths of clepsydra time between meridian passages of stars, and reduce this as nearly as possible to true time by a network of astrolabe measurements of angles between stars, reduced by trigonometry to east-west projection. The accuracy available in star positions could not have reached a thousandth part of present-day precision.

Hipparchus it was who realized the great value to posterity of a star catalog, and he made one containing 1,080 stars, which, with Ptolemy's additions, remained standard for 1,600 years.

It was the making of this catalog of stars which led Hipparchus to note that certain stars observed by Timocharis and Aristyllus a century and a half earlier were in his time 2° farther east, measured from the equinox, than they had been 150 years previously. Thus he discovered the precession of the equinoxes, and set for it a value of not less than 36 seconds per annum. Modern observations raise this to about 50 seconds. The causes were found after Sir Isaac Newton laid down the law of gravitation. The earth is a great spinning top. As the attraction of the sun and moon on the earth's equatorial bulge tends to bring the equator into the plane of the ecliptic, they merely set the pole to revolving, just as you do when you try to tip over a spinning top. The attractions of the planets slightly increase the effect.

Hipparchus had worked out a fairly satisfactory theory of the sun's apparent motion, assuming the earth stationary. It involved circular orbits only. He was not so successful with the moon's motion, and finding the motions of the planets too obscure, he set himself deliberately to making regular observations of their positions which could be used by posterity, if not by himself, to ascertain their true behavior. This altruistic attitude well deserves high praise for Hipparchus.

Ptolemy, living over three centuries later, expressed the highest admiration for Hipparchus and employed that master's observations and discoveries with those of other philosophers to compose the great system known as the Ptolemaic, which is described by him in the Almagest. Ptolemy's greatest original contribution is in his system for the moon's and the planetary motions. Retaining the hypothesis of circular orbits and assuming a stationary central earth, he required a very great complexity of cycles, epicycles, eccentrics, deferents, and equants. He was content with a mathematical system or fiction by means of which the positions of the planets among the stars could be predicted. It is not to be supposed that he regarded this complexity as a real mechanism. In fact, until the rise of Kepler and Newton, no understanding of the real operation of the solar system was possible. At the cost of immense labor, and great shrewdness of mathematical analysis, Ptolemy obtained a very fair representation of the lunar and planetary motions, as accurate perhaps as the observations available to him.

Throughout the Middle Ages, Ptolemy was regarded as final authority in astronomical matters, and little was added to the astronomical edifice built up by the Greek philosophers as finished by

Ptolemy. The Arab astronomers, Albategnius, Abul Wafa, Ibn Yunus, Arzabel, Nassir Eddin, and the Tartar, Ulegh Begh, made some observations of value, computed tables of planetary and other positions, and kept alive the knowledge of the works of the Greeks. But they added very little of original discovery to the body of astronomical knowledge. Indirectly, however, by their introduction from India of our present system of writing numbers, which we still call the Arabic notation, they conferred an immense boon upon astronomy.

Regiomontanus, with his master Purbach and his pupil Walther, in the latter half of the fifteenth century, published in Nurnberg a treatise on planetary theory, invented the method of lunar distances for determining longitude at sea, and published for many years almanacs giving astronomical information. He was invited to Rome to reform the calendar, but died there at the age of 40.

Here then we come to the end of the astronomical knowledge of Shakespeare's time. The Greeks and earlier observers had proved the earth and moon to be spheres, and had inferred that the other heavenly bodies were spheres also. They had devised means of determining latitude, the length of the year, the times of the equinoxes and solstices, and had discovered the periodicity of eclipses. The planets from Mercury to Saturn were known, and their curious motions in advance and in retrograde among the stars had been observed for many centuries. The motions of the sun and moon with respect to the stars were also long observed. By the theorems of geometry, amplified by some of the powers of trigonometry, ingenious, yet fatally complex theories of the celestial motions had been worked out. Such obscure phenomena as the precession of the equinoxes and the various inequalities of the apparent motions of the sun and moon had been discovered.

All of this was done without the telescope or the exact clock. No sufficient accuracy was possible without them to build a true edifice of astronomical theory. Neither was the cloud of ignorance so far lifted as to reveal to most men the improbability of the claims of astrology. Shakespeare showed his superiority of mind by declining to believe that twinkling stars could order human destiny. He made use of other men's beliefs in astrology, nevertheless, to impart mystery and awe to dramatic situations. By the happiest references he often used bits of true or fanciful astronomical lore to make facets of gemlike brilliancy shine from out his verse. What added beauties he would have created had he possessed the knowledge of the Universe that awes us now, it is difficult to imagine.

I have a mind to end this paper gallantly by quoting some lines from the plays to present Shakespeare's heavenly outlook vividly.

From Troilus and Cresida, Act 1, Scene 3:

>The heavens themselves, the planets, and this centre,
>Observe degree, priority, and place,
>Insisture, course proportion, season, form,
>Office, and custom, in all line of order;
>And therefore is the glorious planet Sol
>In noble eminence enthron'd and spher'd
>Amidst the other; whose medicinable eye
>Corrects the ill aspects of planets evil,
>And posts, like the commandment of a king,
>Sans cheek to good and bad.   But when the planets
>In evil mixture to disorder wander,
>What plagues and what portents! what mutiny!
>What raging of the sea! shaking of earth!
>Commotion in the winds! Frights, changes, horrors,
>Divert and crack, rend and deracinate
>The unity and married calm of states
>Quite from their fixture!

From Henry VI, First Part, Act. 1, Scene 1:

>Comets, importing change of time and states,
>Brandish your crystal tresses in the sky,
>And with them scourge the bad revolting stars
>That have consented unto Henry's death.

From Henry VI, Second Part, Act 4, Scene 4:

>Hath this lovely face
>Rul'd, like a wandering planet, over me,
>And could it not enforce them to relent,
>That were unworthy to behold the same?

From Henry VI, Third Part, Act 2, Scene 1:

>See how the morning opes her golden gates
>And takes her farewell of the glorious sun!
>How well resembles it the prime of youth
>Trimm'd like a younker prancing to his love!

From Midsummer Night's Dream, Act 3, Scene 1:

>The moon methinks looks with a watery eye,
>And when she weeps, weeps every little flower.

From Romeo and Juliet, Act 2, Scene 2:

>Two of the fairest stars in all the heaven,
>Having some business, do entreat her eyes
>To twinkle in their spheres till they return.
>What if her eyes were there, they in her head?
>The brightness of her cheek would shame those stars,
>As daylight doth a lamp; her eyes in heaven
>Would through the airy region stream so bright
>That birds would sing and think it were not night.

From Julius Caesar, Act 2, Scene 2:

> When beggars die there are no comets seen;
> The heavens themselves blaze forth the death of princes.

From Richard II, Act 2, Scene 4:

> Ah, Richard, with the eyes of heavy mind
> I see thy glory like a shooting star
> Fall to the base earth from the firmament.

Lastly, from King John, Act 4, Scene 2:

> To gild refined gold, to paint the lily,
> To throw a perfume on the violet,
> To smooth the ice, or add another hue
> Unto the rainbow, or with taper-light
> To seek the beauteous eye of heaven to garnish,
> Is wasteful and ridiculous excess.

PLATE 1

WILLIAM SHAKESPEARE.

PLATE 2
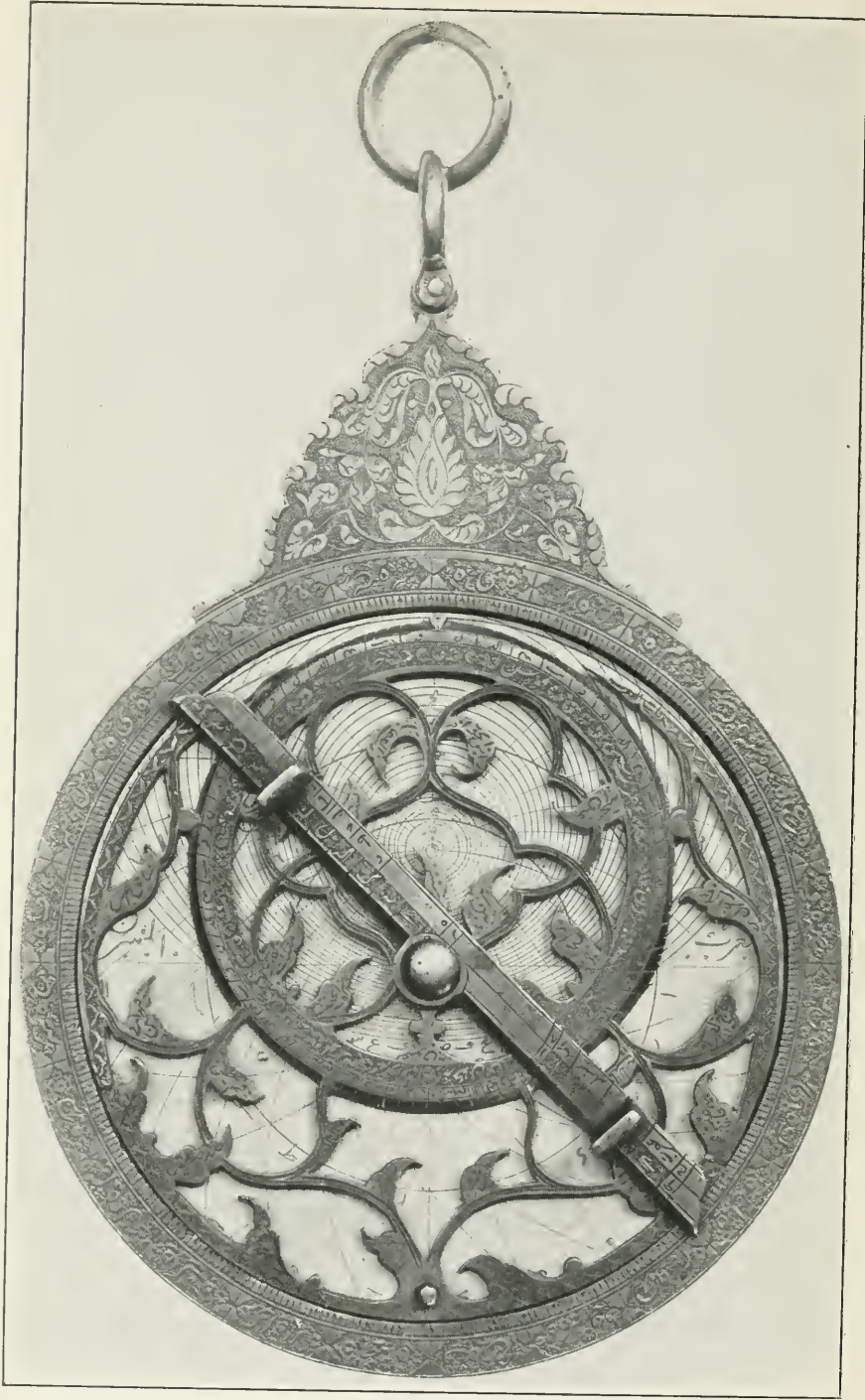
A PERSIAN ASTROLABE.
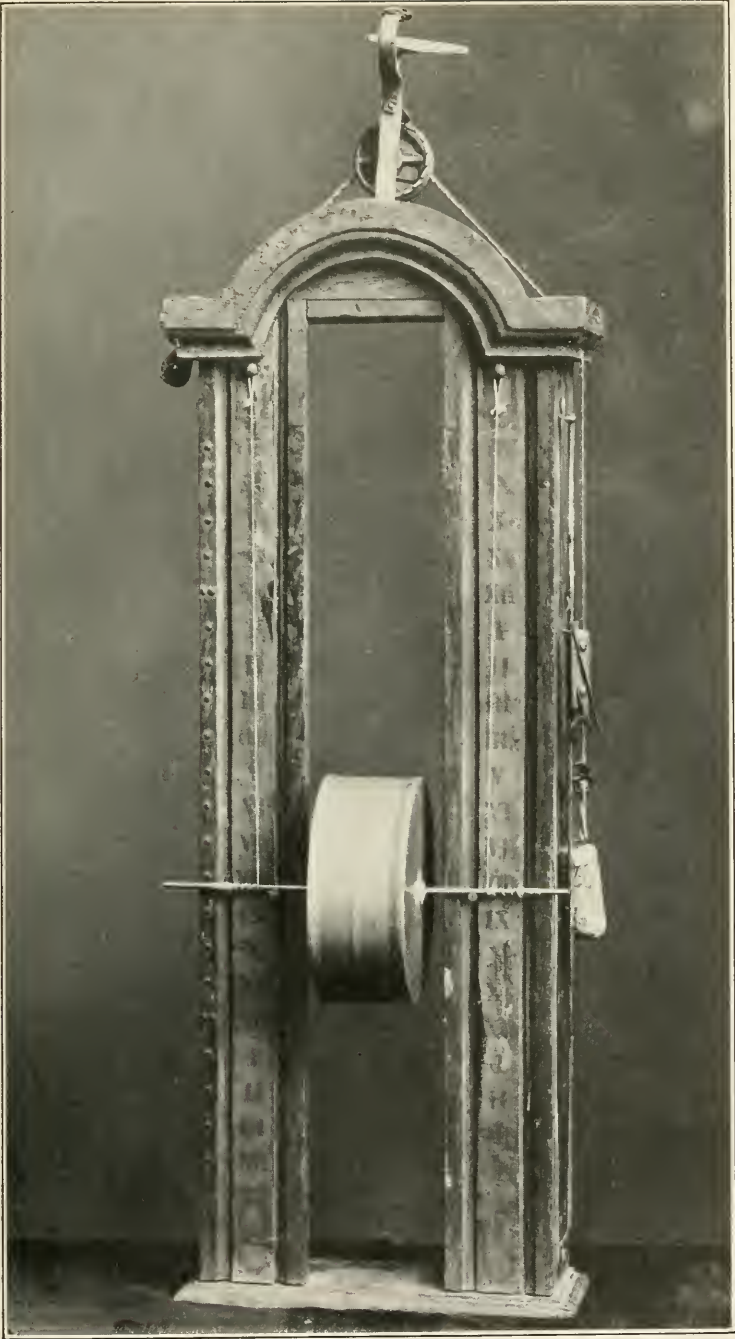
PLATE 3

CLEPSYDRA, OR WATER CLOCK.
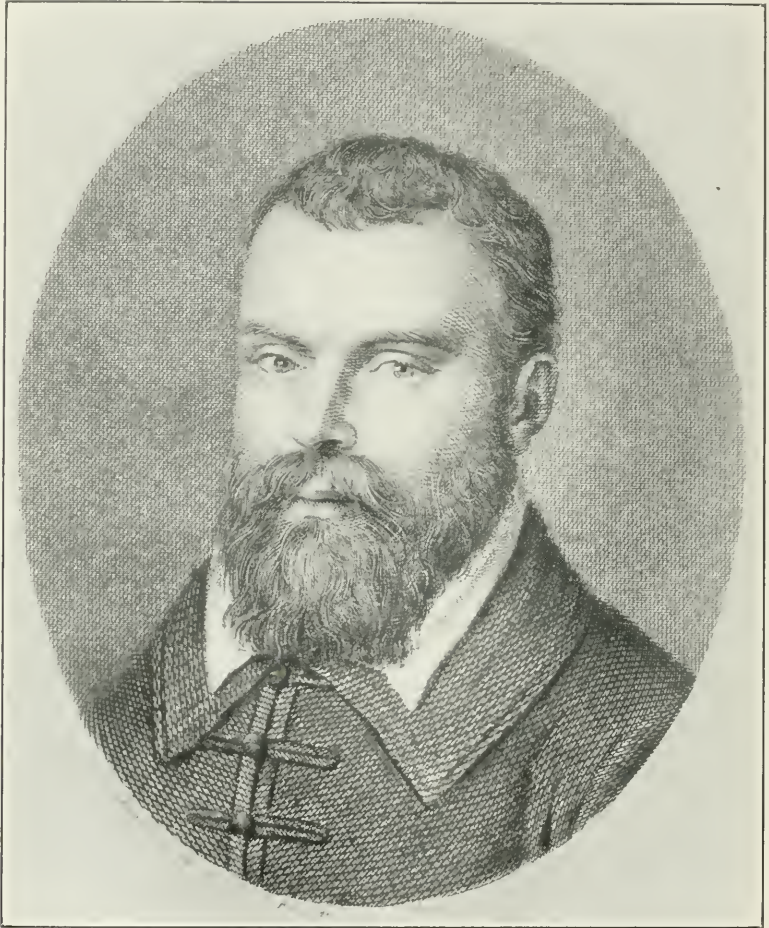
GALILEO GALILEI, INVENTOR, OBSERVER, PHILOSOPHER.

PLATE 5

SIR ISAAC NEWTON.
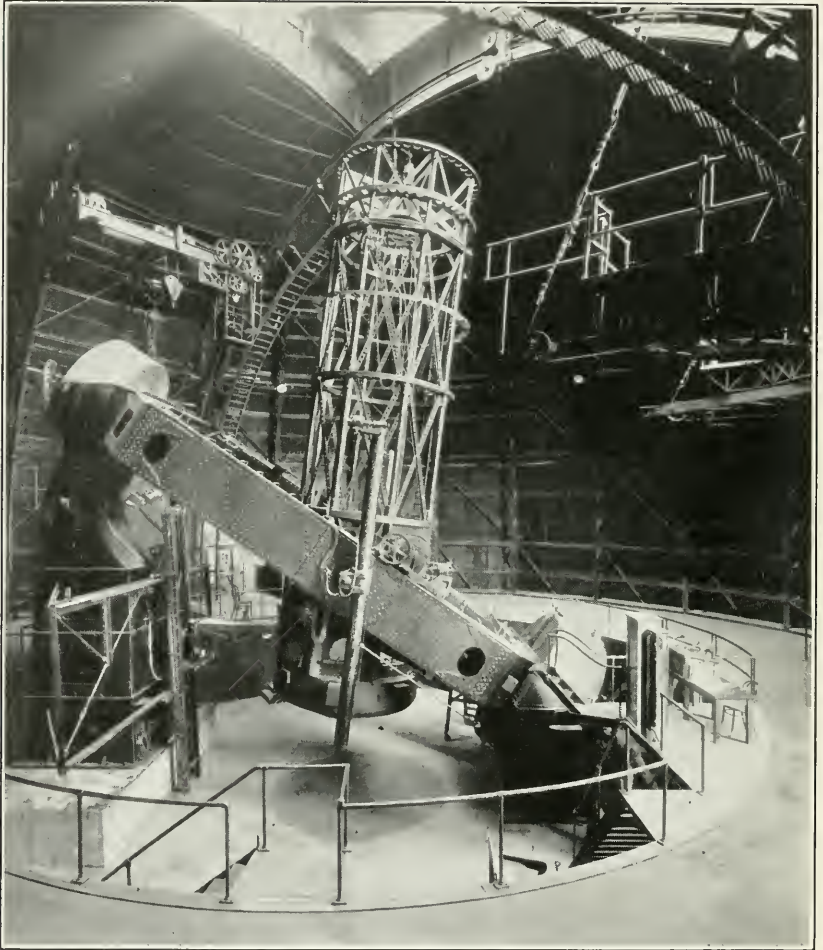
PLATE 6

THE 100-INCH TELESCOPE OF MOUNT WILSON OBSERVATORY.

The world's greatest telescope.

THE SIZE AND AGE OF THE UNIVERSE [1]

By Sir James Jeans, F. R. S.

[With 2 plates]

It has often been said that the history of the race is that of the individual writ large, and this remark is specially applicable to the question of the size of the universe. The new-born child is unable to form an adequate conception of the size of the world, probably because it takes its cradle or its nursery as its unit of measurement. It was the same with the human race in its infancy. Taking for granted that the earth was the central and most important part of the universe, it somewhat naturally supposed that the earth was comparable in size with the whole universe.

EARLY DISCUSSIONS OF THE PROBLEM

Peering into the dimly lit recesses of early science, we see the gradual crumbling away of this belief. In the sixth century B. C., Pythagoras taught that the earth was globular in shape; and in the fourth century B. C., Heraclides of Pontus explained that the apparent rotation of the heavens arose from the rotation of this globular earth under the stars. Such teachings as these inevitably led men to revise their estimates both of the relative size and relative importance of the earth. In the third century B. C., we find Aristarchus of Samos making the first attempts to estimate the size of the universe by the really scientific method of exact measurement. He saw that when the moon was exactly half illuminated, the line from the sun to the moon must be perpendicular to the line from the moon to the earth. Thus in the triangle formed by the sun, the earth and the moon, one angle is a right angle, while another, that at the earth, can readily be measured by observation taken on earth. In this way Aristarchus hoped to obtain the relative lengths of the sides of the triangle in question, and so also the relative distances of the sun and moon.

His theory was perfect, but his observations very faulty. Actually the angle at the earth differs from a right angle by only about 9

minutes of arc.   Aristarchus estimated it to be 3°, and so concluded that the sun was only about 20 times as distant as the moon—actually it is 400 times as distant.

He also made estimates of the actual distances.   Thanks to the genius of Anaxagoras, the nature of eclipses was already well understood.   It was known that the darkness which spreads over the moon at an eclipse is the shadow of the earth.   Aristarchus, knowing that the sun was many times more distant than the moon, saw that this shadow must be approximately of the same dimensions as the earth itself—it was a circle of the size of the earth seen at the distance of the moon.   Knowing the size of the earth, it was an easy matter to compute the distance of the moon.

Once again Aristarchus relied on a series of erroneous measures. He estimated that the earth's shadow had only twice the diameter of the moon—actually it has three times this diameter.   Also, the moon subtends an angle of half a degree in the sky, but Aristarchus took the angle to be 2°, and so got erroneous values for the moon's distance as well as for its size.   Clearly exact measurement was not his strong point, yet he was the first to demonstrate the order of magnitude of astronomical distances.

Aristarchus made an even more important contribution to the large-scale problems of astronomy.   He showed, by reasoning very similar to that used by Copernicus 1,800 years later, that the earth revolved in a circular orbit about the sun.   He then argued that, as the fixed stars appeared in spite of this motion to retain fixed places in the heavens, they must be at immeasurably great distances from the earth, saying that the distances of these stars "bore the same relation to the earth's orbit as the radius of a sphere bears to its center"— in other words, the whole solar system was a mere point in the immensity of space.

I need scarcely remind you how, in the second century after Christ, these enlightened views were challenged and temporarily vanquished by Ptolemy of Alexandria.   Ptolemy argued that if the earth were rotating, objects at the Equator would be in the most violent rotation, and so would fly off into space, since "matter which is in violent rotation does not seem fit to be massed together, but rather dispersed." He went on to say that "long before now the disintegrated parts of the earth would have been dissipated over the heavens themselves, which is very ridiculous."   He also said that, if the earth were rotating, a stone dropped to earth would not reach its destined place, because the earth would be moving eastward under it all the time it was falling.   He said further that if the earth were rotating, the clouds would move over our heads from east to west as a consequence of this rotation.   Clearly he had never stood in the track of the

trade-winds and seen the clouds moving in endless procession from east to west as a result of the very rotation he was trying to discredit.

It was not until 1543 that these arguments were refuted by Copernicus. Ptolemy's argument had been that the earth cannot be rotating, because if it were it would fly to pieces; thus the nightly motion of the stars must result from the rotation of the heavens themselves. Yet, if the whole heavens rotated once every 24 hours, they must have an even higher tangential velocity than he, Copernicus, wished to attribute to the earth. Why then, asks Copernicus, do not the heavens themselves fly to pieces? It was a shrewd thrust, but Copernicus was betrayed into pursuing his stricken enemy too far. For he went on to inquire whether the heavens really could be expanding under the centrifugal force of their rotation; and his argument has a strange ring of 1935 about it. He scornfully asks what the heavens could possibly be expanding into, for as they are the whole universe, there can be no space beyond them into which they could expand.

The theories of Copernicus fared better than those of Aristarchus, the two principal reasons for their greater success being that printing and the telescope had been invented in the meantime. Two-thirds of a century after Copernicus published his book, the telescope of Galileo had virtually established the truth of his doctrines, and the sun replaced the earth as the fundamental unit of the universe. Ten years before Galileo had looked through his first telescope, Giordano Bruno was maintaining that the stars were similar objects to the earth, moon, and planets—as Pythagoras had conjectured 2,000 years before. Ten years after, Kepler was saying that they must be similar objects to the sun; and this led to the first real comprehension of the immensity of space. For, if the stars were intrinsically as bright as the sun, they must be at stupendous distances to look so much fainter than the sun. We receive approximately 100,000 million times as much light from the sun as we do from a first-magnitude star such as Altair, Betelgeux, or Aldebaran. Thus, if these stars are comparable with the sun in luminosity, they must needs be about 320,000 times as distant—no smaller distance would be compatible with their faintness. In modern terminology, these first-magnitude stars would be at distances of approximately $1\frac{1}{2}$ parsecs or 5 light-years.

We know now that this method of calculation cannot lead to very accurate results, at any rate in its present crude form, because the supposition that the stars are all of the same candlepower as the sun is very far from the truth—some have more than 10,000 times the candlepower of the sun, while others have less than a ten-thousandth part. But the method admits of almost endless refinement, and in its modern form provides the most useful, and indeed almost the only, method for estimating the distances of very remote objects.

THE MODERN METHOD OF ATTACK

The stars fall into clearly defined categories. As an unassorted whole, they exhibit an enormous range in candlepower, but all the stars in any one category are of approximately the same candlepower, so that we can obtain a reasonably good estimate of a star's distance by considering its apparent brightness in conjunction with the category into which it falls. For the majority of stars, the category is determined mainly by the star's spectrum, but in the case of variable stars, the period of variability is even more important than the spectrum, and leads to results of far greater precision.

To take an instance of the simplest kind, the star Sirius, which looks the brightest in the whole sky, is one of those nearer stars whose distance can be determined by ordinary trigonometrical methods— methods which are the same in principle as those which the surveyor uses to determine the distance of an inaccessible mountain peak. The whole process is, of course, conducted on an enormously larger scale; the surveyor takes a base-line a few miles long on the earth's surface and finds his mountain is a few miles distant, while the astronomer takes as his base-line the diameter of the earth's orbit round the sun—a base-line 186,000,000 miles long—and finds that his star is many millions of millions of miles distant. In this way he finds that the distance of Sirius is 51 million million miles, or 8.65 light-years. Knowing this, we can estimate the distance of all stars which belong to the same category as Sirius; for example, a similar star which looks 100 times less bright must be 10 times as distant, because light falls off as the square of the distance.

Variable stars provide a more reliable method of estimating astronomical distances. For example, the star δ Cephei is found by the ordinary surveyor's method to be about 60 times as distant as Sirius. All stars which have the same period of variability as δ Cephei are found to have about the same candlepower, so that again their distance can be estimated from their faintness. As these variable stars are enormously bright, they can be seen to immense distances—hence their special value as indicators of astronomical distance.

We can test these methods in various ways. The obvious one is to find a group of stars which are already known to be all at the same distance, and see whether each of the stars tells the same story as to the distance of the group. Such groups of stars are to be found in the globular clusters, the Magellanic clouds, and in the nearer of the extragalactic nebulae.

In these last objects, even the vivid Cepheid variables look very faint. Nevertheless they are visible, and their feeble brightness can be measured with considerable accuracy in a large telescope. In this

way we find that the distance of the nearest of these nebulae is about 770,000 light-years.

This is the nebula M 33 in the constellation Triangulum. The second nearest nebula is the well-known "Great" nebula in Andromeda; this is at a distance about 3 percent greater. In this last nebula, no fewer than 40 Cepheid variables can be detected, but as we pass to more distant nebulae, the number of identifiable Cepheids naturally decreases, and this particular method becomes less reliable. Finally it fails altogether through the impossibility of discovering Cepheid variables at all.

Yet many stars are even brighter than Cepheid variables, and these enable us to carry on with the same method to even greater distances.

In table 1, the second column shows the distances of eight near objects as determined from the Cepheid variables observed in them. The last column shows the candlepower of the brightest stars observed in these objects, that of the sun being taken as unity.

TABLE 1

Object	Distance in light-years	Candlepower of brightest star (Sun=1)
Large Magellanic cloud	85, 000	100, 000
Small Magellanic cloud	95, 000	18, 000
Globular cluster N. G. C. 6822	620, 000	15, 000
Nebula M 33	770, 000	29, 000
Nebula M 31 (Andromeda)	800, 000	18, 000
Nebula M 101	1, 300, 000	22, 000
Nebula N. G. C. 2403	2, 000, 000	22, 000
Nebula N 81	2, 400, 000	18, 000

With one exception, the brightest star in each of these objects has about 20,000 times the candlepower of the sun. Now stars can be identified in 40 nebulae in all, and if we assume that in each of these the brightest star has about 20,000 times the candlepower of the sun, we can immediately estimate the distance of these nebulae also.

We have been gradually moving farther out into space, and if we still continue our journey, we come in time to nebulae in which even the brightest of stars are invisible. How then can we discover the distances of these nebulae?

The answer is that the nebulae—like the stars—appear to be built to pattern. When two stars show the same spectrum and the same period of variability, they belong to the same category, and are of approximately the same candlepower. In the same way, when two nebulae show the same build—the same shape and distribution of

relative brightness—they are of approximately the same candle-power. We reach this conclusion from a study of the nearer nebulae, whose distance can be ascertained, and then assume that it is true of the farther nebulae also. Thus the faintness of the nebulae gives a measure of their distance, and in this way we can estimate the distances of even the faintest of visible nebulae.

THE VISIBLE UNIVERSE

Using this method, we find that the faintest nebulae which are visible in our telescopes are at a distance of about 240 million light-years. Before we proceed further, let us try to see all this in proportion—let us make a small-scale model on the scale of 2 million light-years to the inch. Then our visible universe will be a sphere 20 feet in diameter. Our galaxy is a small disk of the size of an average pinhead—perhaps one-tenth inch in diameter. The naked-eye stars are all contained in a sphere of about one six-hundredth inch radius—a mere speck of dust. Our sun is a single electron, and the earth is a millionth part of an electron.

There is no reason to suppose that this sphere of 240 million light-years radius contains the whole of the universe; we may be sure that a larger telescope would show still fainter, and, therefore, still remoter nebulae, so that there is no means of fixing the total size of the universe—if it has a finite size—in this way. We must turn to other, and less direct, methods.

RELATIVITY THEORY AND THE UNIVERSE

According to the theory of relativity, space curves back into itself, so that the total volume of space is finite—just as the total area of the earth's surface is finite. If the earth's surface were plane, the area within a distance x of any given point, say Charing Cross, would be exactly proportional to x^2. But, because of the curvature of the earth's surface, the actual area increases less rapidly than x^2. A circle 1 mile in radius has an area of 3.1416 square miles, but a circle 100 miles in radius has an area of less than 31,416 square miles. If space is curved in a similar way, the volume of space which lies within a distance x of the earth would increase less rapidly than x^3, so that if the nebulae are uniformly distributed in space, the number of nebulae would also increase less rapidly than x^3.

Efforts are being made at Mount Wilson to examine whether the number of nebulae falls off in this way at great distances, but so far the number appears to vary approximately as the cube of the distance—there are no signs of falling off as yet. Indeed, preliminary statistics which have only reached Great Britain within the last few days seem to indicate the exact reverse. This may perhaps mean that

PLATE 1

A GROUP OF NEBULAE IN THE CONSTELLATION PEGASUS.

The three nebulae near the center of the plate are of approximately the same build, and as they all appear to be of the same size and brightness, we conclude that they are all at the same distance, and so form a close group in space.

PLATE 2

A GROUP OF NEBULAE IN ANOTHER PART OF THE CONSTELLATION OF PEGASUS.

One of the nebulae looks far larger and brighter than the others, whence we conclude that it is much nearer to us, so that these nebulae do not form a close group in space.

we live in a part of the universe which is only sparsely filled with nebulae, so that we come to a greater density of nebulae when we go far from home. But a more likely interpretation is that the present observational material is inadequate for statistical treatment. We may hope that the new 200-inch telescope will solve the problem for us in due course. In the meantime, the only inference that we may legitimately draw from our present telescopic observations is that, in all probability, the nebulae extend very much further than the 240 million light-years to which our telescopes can penetrate.

If the effect just mentioned had been observed, it might have been possible to form an estimate of the total volume of space. As this method is not available, we must fall back on other, and less reliable, methods.

According to an earlier form of the theory of relativity, there was a quite simple relation between the total volume of space and the average density of matter in space. Unhappily, it is not easy to estimate the density of matter in space with any accuracy, but it is at least possible to assign upper and lower limits between which it must lie. This, of course, leads to upper and lower limits for the total volume of space; and calculation showed that if this theory were sound, space was immense in comparison with that part to which our telescopes can reach. The 240 million light-years to the farthest visible nebulae is only a minute fraction—perhaps a three hundredth part—of the radius of space. Or, to say the same thing in another way, light takes 240 million years to travel from the farthest visible nebulae to us, but would take 500,000 million years to complete the journey round space and get back to its starting point.

This particular development of the theory of relativity has fallen into disfavor of recent years; it is still possible that it may give a rough approximation to the truth, but it seems quite certain that it is not the whole truth. Other theories have suggested radii of space of about 2,000 and 10,000 million light-years respectively, but it is hard to feel much confidence in these estimates. All that we can say with any confidence is that the dimensions of space are probably far greater than the 240 million light-years to which our telescopic eyes can see. Einstein's latest conjecture is that space may after all, his earlier theories notwithstanding, be of literally infinite dimensions.

THE AGE OF THE UNIVERSE

The question of the age of the universe is of a somewhat different nature. There are a great number of different ways of estimating this age; none of them are completely trustworthy, and unhappily they appear to lead to inconsistent results. Stated in its crudest and most obvious form, the problem is, of course, that of examining

how far we can trace back the universe into the past, and it is perhaps not surprising that the further we go the less certainty we find.

The big telescope at Mount Wilson shows us objects in space whose light has taken 240 million years to reach us. When we turn the telescope on to these objects we see them, not as they are now, but as they were 240 million years ago. These parts of the universe, then, must have been in existence 240 million years ago, and we seem justified in concluding that the universe as a whole is more than 240 million years old. Not only so, but these distant parts of space are occupied by objects which do not differ in essentials from those nearer home, from which it seems safe to conclude that the universe has not altered greatly in the past 240 million years; in other words, this period is only a small part of the evolutionary life of the universe, so that the age of the universe is probably many times 240 million years.

A study of our own earth confirms this conclusion. Geology can reconstruct for us the physical conditions of 240 million years ago, and we see that, broadly speaking, they were very similar to those prevailing today. This not only shows that the earth is more than 240 million years old, but also that the sun has changed but little in the past 240 million years. Thus the sun, and so also the universe of which the sun forms part, must probably have an age of many times 240 million years.

By analyzing the radioactive properties of rocks of various kinds in the crust of the earth, we can discover the length of time which has elapsed since these various rocks solidified. The oldest rocks of all show ages ranging up to 1,750 million years since solidification. Thus we may safely conclude that the universe is at least 1,750 millions of years old.

THE EXPANDING UNIVERSE

For the next piece of evidence, we must return to the extreme depths of space. We believe the great extragalactic nebulae to be galaxies of stars generally similar to our own, and these are found to be receding from our galaxy with immense speeds—the largest speeds we encounter in astronomy, apart from the velocity of light. The greatest so far observed is 42,000 kilometers a second, which is one-seventh of the velocity of light. It is found to be a general rule that the most distant nebulae are receding the most rapidly, and the speeds of the various nebulae are proportional to their distances from us. This is shown in figure 1, which embodies results recently obtained by Hubble and Humason at Mount Wilson. The abscissae represent the distances of various nebulae and groups of

nebulae at distances ranging up to about 40 million parsecs (130 million light-years); the ordinates represent the observed velocities of recession of these nebulae expressed in kilometers per second. It is at once seen that the velocities are very approximately proportional to the distances of the nebulae.

The theory of relativity provides a very simple explanation of these observed motions of the extragalactic nebulae, and of the law obeyed by the speeds of the nebulae at different distances. It is, in brief, that space itself is uniformly expanding, and that the
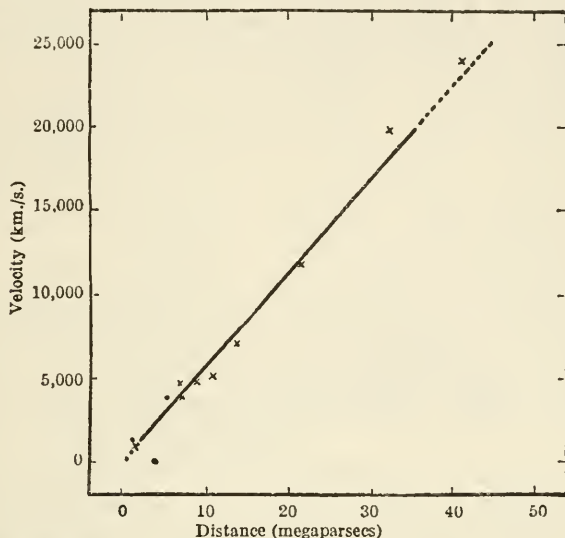
FIGURE 1.—Extragalactic nebulae. Velocity-disturbance relation (Hubble). Isolated nebulae (grouped). ✕, clusters of nebulae.

nebulae embedded in it indicate the motions of space, much as floating straws indicate the currents in a stream. If this is the true explanation, then the nebular motions show that space is at present expanding at such a rate that its linear dimensions double every 2,000 million years—which, let us notice in passing, is just about the probable age of the earth. But the theory of relativity goes further than this, and tells us that space is very unlikely to expand continually at a uniform rate. Certain assumptions suggest that the expansion increases, approximately at least, in geometrical progression with the time. If this is the true law, then the present nebular motions show that space doubles its linear dimensions every 1,400 million years. In other words, 1,400 million years ago space had only half its present linear dimensions; 2,800 million years ago only a quarter of its present linear dimensions; and so on.

We must not, however, go on in this way forever. It would take an infinity of time to reduce space to a point, but this is unimportant, for obviously we must not reduce space to a point; we must stop somewhere before we reach that stage. Detailed mathematical investigations, too complicated even to summarize here, seem to suggest that space cannot have been expanding for more than about 100,000 million years. This figure is, however, very uncertain, and in any case provides no conclusive evidence as to the age of the universe. For mathematical investigation also shows that the present period of expansion may well have been preceded by a period of contraction. Indeed the mathematical equations admit of solutions of two different types. In one, the present epoch of expansion is preceded by an earlier epoch of contraction, and no limits can be set to the possible duration of this. In the other, the present epoch of expansion is only one of a great number of epochs of regularly alternating contractions and expansions, and no limit can be set to the possible number of these epochs. This line of discussion, then, can tell us nothing definite as to the age of the universe.

It may, of course, be argued that, even though definite evidence is lacking, considerations of probability fix a probable limit to the age of the universe. The general line of argument would be that in the last 1,000 million years, the dimensions of space have changed very appreciably—probably by about 60 percent—so that the time-scale of change is one of thousands of millions of years, and it is likely that the total age must also be measured in terms of thousands of millions of years. To take a parallel instance, if a zoologist captured a new kind of animal, of entirely unknown species, and found that its weight increased by 60 percent in a month, he would probably conclude, rightly or wrongly, that the creature was not many months old. If a tree increases its height by 60 percent in a year, the botanist may be fairly sure that it is not many years old. The argument undeniably carries some weight, but we must be careful not to overrate it. In brief, we must remember that the universe is neither an animal nor a tree. The population of England has increased by 60 percent in the last half-century, but we should not be justified in concluding that England is only a few half-centuries old. The brightness of the star Mira Ceti has changed by about 60 percent in the last month, but we must not conclude that Mira Ceti cannot be more than a few months old. Thus general considerations of probability can at best give a presumption, and not a very strong one at that.

THE MOTIONS OF THE STARS

Another line of argument, which seems to me far more convincing than the foregoing, leads to very different conclusions. If I set a

pendulum swinging, it comes to rest after a short time. It has been reduced to rest by its continued impact with molecules of air; in brief, it has shared its energy with these molecules.

Actual experiment may show that this pendulum comes to rest in a few minutes, but I could calculate this out without experiment. All I need to know is the size and weight of the pendulum, and the density of the air in which it swings. Thus if I come into the room and find the pendulum swinging vigorously, I can conclude, from purely abstract calculations, that it has not been swinging for many minutes; it must have been set into motion only a few minutes ago. But if I find that it is at rest, and that hundreds of other similar pendulums are also at rest, I can conclude that they have stood undisturbed for many minutes—they may previously have been in motion, but if so, they have already shared their energy with the surrounding molecules of air.

This tendency to sharing energy pervades the whole of physics and prevails also in astronomy. The laws which govern the motions of the stars show that these also must share their energies with one another, and if they have been left undisturbed for a sufficiently long time, this sharing of energy will be complete. We can calculate how long a time is needed for the process to be effected, and it proves to be a matter of millions of millions of years. Thus if we find that the stars have already shared their energy, we know that they must be millions of millions of years old.

The method admits of greater refinements. Suppose I have a row of pendulums of different sizes and weights, one of which comes approximately to rest in 2 minutes, while the next requires 4 minutes, others require 6, 8, 10, and 12 minutes, respectively. Suppose a cataclysm of some kind occurs—say, an earthquake—and after a time I come into the room and find that the 2, 4, and 6 minute pendulums have already come to rest, while the 8, 10, and 12 minute pendulums are still swinging with varying degrees of force. It is reasonable to conclude that the cataclysm occurred between 6 and 8 minutes ago. With a sufficient number of pendulums, it might be possible to fix the time with considerable precision.

Now the different kinds of stars form just such a range of pendulums. Fortunately, they share their energies at very different rates. When we proceed to observation, we find that in actual fact some types of stars have already shared their energies almost completely, both with other stars and with one another; for other types the process has barely begun. This is shown in the three following tables.

TABLE 2.—*Orbits of visual binaries classified by eccentricity*

Limit of e	Observed	Equipartition of energy
$e < 0.1$	0	2
$e < 0.2$	11	9
$e < 0.3$	20	21
$e < 0.4$	34	37
$e < 0.5$	58	58
$e < 0.6$	83	83
$e < 0.7$	89	113
$e < 0.8$	102	148
$e < 0.9$	109	187
$e < 1.0$	116	231

Table 2 is concerned with observations of 116 stars; for 83 the eccentricity of orbit is less than 0.6, and for 33 stars it is greater than 0.6. The last column shows the statistical distribution of eccentricities we should find in a group of stars in which the process of energy-sharing was complete, the group being chosen to be of such a size that there are again 83 stars of eccentricity less than 0.6. A comparison of this and the preceding column shows that the energy-sharing process is fairly complete up to eccentricity 0.6, but that for eccentricities higher than 0.6, there is very little evidence of energy-sharing. These stars of high eccentricity correspond to very slow "pendulums", but we must not overlook that our table may be incomplete on the observational side, since binary stars of eccentricity greater than about 0.6 are difficult to detect and still more difficult to measure.

The visual binaries of eccentricity less than about 0.6 form a range of pendulums in which the process of energy-sharing requires a time of millions of millions of years. In another class of binary stars, the spectroscopic binaries, the components lie much closer together—so close in fact that the gravitational forces from other stars have very little effect in modifying their orbits. In these stars, the process of energy-sharing is a matter of hundreds of millions of millions of years at least. Table 3 contains statistics as to the orbits of these stars. We see at once that there is no appreciable sharing of energy.

TABLE 3.—*Orbits of spectroscopic binaries classified by eccentricity*

Limit of e	Observed	Equipartition of energy
$e < 0.2$	78	12
$e < 0.4$	96	50
$e < 0.6$	112	112
$e < 0.8$	118	199
$e < 1.0$	119	311

Finally, the linear motions of ordinary single stars provide yet another range of "pendulums." We know that the molecules in a gas tend to share their energy, until finally all types of molecules, big and small, light and heavy, have, on the average, the same amount of energy. In the same way the stars tend to share their energy, and groups of stars of different masses form a range of pendulums, the most massive stars sharing their energy most slowly and the lightest the most rapidly.

Table 4 gives the average linear velocities of stars of different masses as determined by Seares at Mount Wilson. We see that all except the most massive stars are well on toward equipartition of energy, all having an average energy which is not very far from 3,750 in the units we are using.

TABLE 4.—*The linear velocities of stars of different masses*

Mass of star	Average velocity	Energy
7. 6	15. 3	1, 785
5. 5	26	3, 675
4. 0	30	3, 550
2. 5	36	3, 240
1. 5	48	3, 550
1. 0	65	4, 070
. 7	78	4, 420
. 6	76	3, 470

These and various other "pendulums" agree in suggesting that we must assign to the universe an age of 5 to 10 millions of millions of years.

THE SOURCE OF STELLAR ENERGY

Let us now consider the state of things 5 millions of millions of years ago. Observation shows that the sun is at present radiating energy away at the rate of about 250 million tons a minute. This time yesterday, then, it weighed 360,000 million tons more than now. A million million years ago, it weighed a very great, but still calculable, number of tons more than now; it was about 6 percent more massive than now; and, because of this, it was also a brighter star than now, radiating not 250 million tons a minute, but about 300 million tons a minute. After adjusting our calculations for such considerations as this, we find that 5 million million years ago, the sun was probably many times as massive as now and many times as bright. In the intervening period, it has been gradually getting rid of its mass in the form of radiation, until it is reduced to a mere relic of its former magnificence.

A few years ago, it was difficult to believe that the sun could produce its radiation by the actual annihilation of its substance, but in these few years the short-lived positive electron, or "positron", has been detected in the laboratory. This has given us every reason for thinking that the transformation of matter into radiation is continually going on in ordinary terrestrial matter, as well as the converse process of the creation of matter out of the energy of radiation. With this source of energy to call on, there is no longer any objection to our assigning ages of millions of millions of years to the stars.

It was not easy to visualize the vastness of astronomical space, and it is even less easy to conceive of the immensity of astronomical time. A fairly lengthy book contains about 200,000 words averaging five letters each. Let us take the whole of such a book to represent the age of the earth. Then the whole of civilization is represented by the last word or two, and the whole of the Christian era by something less than the last letter. A single lifetime is a good deal less than the final full stop with which the book ends. Such is the age of our own planet, and, whatever view we take, the age of the whole universe, on the same scale, is a matter of volumes. If the view I put forward last is correct, it must be represented by a library of some thousands of volumes.

THE EARTH, THE SUN, AND SUNSPOTS [1]

By Loring B. Andrews

Instructor in Astronomy and Executive Secretary of the Harvard Observatory

[With 2 plates]

About thrice a year there lies upon my desk a letter which typi-
cally reads in the following fashion: "I would greatly appreciate
it if you could send me a list of dates of maximum and minimum
sunspot activity running back to around 1850. I believe I have dis-
covered a correlation between sunspot activity and business activity,
but, inasmuch as I have been unable to get the sunspot periods accu-
rately, I am unable to carry the correlation back over a sufficiently
long period of time. I would greatly appreciate any help you can
give me along these lines."

This letter is the stimulus to take once again from the observatory's
library the volume I have so frequently fingered, the Astronomische
Mitteilungen of the Zürich Observatory, to open it at no. 132, page
67, and to extract therefrom the list of sunspot maxima and minima
for as long a period of time as the writer requests. I find, for example,
that since 1900 there has been maximum spottedness at the following
times: 1906.4, 1917.6, and 1928.4; and minimum spottedness at 1901.7,
1913.6, 1923.6, and 1933.8. An arithmetician will inform you that these
figures tell of a variation of spottedness of the sun possessing a pe-
riod of 10.8 years, or, as one commonly states it, a period of 11 years.
A further perusal of the table—and it lists the maxima and minima
back to 1610—reveals that this period is not reproduced with clock-
like precision. One notes a minimum interval of 7.3 years and a
maximum interval of 15.0 years. In fact the long-term average for
the period of sunspot variation is 11.13 years. Other idiosyncrasies
are noted in the heights of maxima and the depths of minima.

The average person of today is endowed with sufficient intelligence
to avoid looking directly at the sun without protection for the eyes.
Yet it was not always so. We are informed that the very early Chi-
nese astronomers observed the sun with the naked eye and discovered

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thereon large black areas, blemishes on the face of a perfect, luminous sphere. Today one may with fair frequency similarly observe with the naked eye dark areas on the surface of the sun, provided the eye is suitably protected by a piece of dark glass or an overexposed bit of photographic film. These dark areas are the sunspots, impermanent markings, subject to the variation in number previously outlined. They represent evidence of some deep-lying solar activity, the exact nature of which astronomers do not yet know.

Research has conclusively demonstrated that sunspots are huge solar cyclones, whirlwinds in the solar atmosphere, accompanied by pronounced magnetic conditions. Each sunspot, assumedly as the result of the whirling of electrically charged particles within it, is a huge magnet. Each such disturbed area of the solar atmosphere may be simple or complex in appearance. One speaks of single spots, the ultimate state of simplicity; of bipolar groups, whereby is meant, in general, two neighboring disturbances, the one preceding, the other following, along a solar parallel of latitude; and of complex groups, of which the name is adequately descriptive. The magnetic polarities of the individual centers of activity within an area follow certain general rules that become of increasing complexity of application as one proceeds from single spots to the complex groups.

Sunspots have been termed impermanent markings. Inasmuch as they are of the nature of solar cyclones, they should be as impermanent as their terrestrial counterpart. The average life of a disturbance of this nature is 2 or 3 months. The longest-lived spot on record is that of the years 1840 and 1841, which persisted for 18 months. The shortest-lived disturbance is usually of but a few hours' duration.

Such a variable phenomenon requires daily observation, even as daily records are made of terrestrial weather. It is to a certain extent the equivalent of keeping a daily account of the solar weather, though there is no attempt at a detailed prediction of what the morrow will bring. It is for this reason that one activity of the Department of Astronomy at Harvard has been the daily photography of the sun, when the weather permits, a procedure that has been followed since the autumn of 1926. To the present over 1,800 photographs have been filed.

Some attempts have been made to ascertain whether certain regions of the solar surface represent weak areas wherein sunspots are most likely to reoccur. The results are but poorly supported by the direct evidence. Of one result, however, astronomers are completely certain. Sunspots occur only within certain limits of solar latitude. Beyond the confines of the two belts defined on the ap-

parent solar surface by solar latitudes 6° and 40°, the one in the Northern Hemisphere, the other in the Southern, spots but rarely occur. The first spots of a new outburst of solar activity appear near the high latitudes of the belts, and, as the cycle progresses toward maximum spottedness, the average latitude of these disturbances progresses constantly toward the lower solar latitudes, reaching the value of 15° at maximum, and continuing onward toward the lower limits of the belts as the cycle declines toward minimum. Thereafter the first evidence of a new cycle is the reappearance of spots near the upper limits of the belts. The causes of this behavior of spots, as well as of the variations of their magnetic properties, are still clothed in mystery.

The aim of this article is, however, not to recount the properties of sunspots as such. Given this manifestation of solar activity, our interest lies in the determination of any possible terrestrial influence. The presence of huge magnetic fields in sunspots results in their acting as howitzers to pour forth charged particles of matter into the interplanetary realm. If the earth is in the range of the howitzer, its atmosphere is the recipient of these particles, and, beyond doubt, electrical phenomena should occur there. The rotation of the sun on its axis in a period of some 25 days prevents the earth's being constantly in the range of a sunspot or sunspot group, and so we look for the evidence of a terrestrial effect primarily when a spot lies near the center of the sun as seen from the earth. When this state of affairs is valid, such terrestrial phenomena as auroral displays, magnetic storms, and effects on long distance radio reception should occur, for they all depend upon the electrical conditions of the atmosphere; and indeed our expectations are fulfilled. All three phenomena show a close correlation with sunspot activity and particularly with the passage of an active sunspot group across the central area of the sun's disk; the aurorae, borealis and australis, perform beautifully, magnetic compasses oscillate to and fro over a small amplitude centered at their normal position, and long distance radio reception is either improved or hampered. In connection with the last of these it should be said that whether reception is improved or hampered depends upon the wave length of the signals and other factors related to radio transmission.

The assumed validity of a correlation of electrical phenomena on the earth and sunspot activity is thus established in a straight-forward manner. The many additional correlations, including the correlation of sunspot activity with weather conditions, the receipt of rabbit pelts, wars, floods, international crises, economic tranquillity and distress, the growth of trees, even with volcanic activity, hardly fall, however, within the category of terrestrial electrical phenomena.

Yet sunspot activity apparently correlates with these terrestrial activities, and the source of the correlation must be sought in other solar phenomena that are correlated in turn with sunspot activity.

Among the solar phenomena which might possibly have an influence on things terrestrial are the intensity of the solar radiation and the nature of the light which the sun sends earthward. Both of these are found to correlate with sunspot activity. At the times of sunspot maximum the earth's receipt of heat from the sun increases over nomal and, when the sunspots are at a minimum, the heat received is below normal. Surely this change in the receipt of warmth by the earth should be noticeable. One would expect that the increased receipt of heat would result in a generally higher terrestrial temperature and a slackened heat input with a generally lower terrestrial temperature, but this is not so. The relationship is exactly the reverse, at least so far as accurate measurements of temperature on the earth are available. The theory commonly given to explain this apparent anomaly is as follows: Increased heat radiation from the sun entails a higher degree of warmth of the earth. High temperatures are, however, conducive of increased evaporation from the water-covered areas of the earth with a resulting higher water-vapor content of the earth's atmosphere. Inasmuch as clouds are the results of the condensation of water vapor, its higher percentage should result in the prevalence of clouds as well as in increased rainfall. Both evaporation and rainfall are cooling phenomena. The net result should be that, when the earth is receiving the greatest amount of heat from the sun, surface temperatures on the earth would be below normal. When the earth's receipt of heat from the sun is at a minimum, the terrestrial effects are the reciprocal of those at sunspot maximum, and terrestrial temperatures should be above normal. A number of correlations are suggested by this line of reasoning. There should be a correlation between sunspots and the prevalence of clouds on the earth, such that at sunspot maximum, cloudiness should be at a maximum too, while at sunspot minimum, cloudiness should be at a minimum. At sunspot maximum, rainfall should be at a maximum, at sunspot minimum, it should be at a minimum. Of course, it is necessary to inject a word of caution, namely, that terrestrial weather, considered in detail, is such an uncertain affair that to differentiate a strictly solar effect from the multitude of terrestrial effects is not the easiest task imaginable.

The ideas of the last paragraph would seem to offer a clue to long-range weather forecasting with a somewhat higher degree of validity than that with which it is done in certain almanacs of wide circulation. There does seem to be a general agreement among meteor-

ologists that solar influences dominate the weather situation of the earth, and the attempts being made at present to discover the clue to long-range weather forecasting have their basis in the study of the output of heat from the sun.

The second correlation between a solar phenomenon and sunspot variation is that of the ultraviolet content of the sun's radiation. At times of sunspot maximum the percentage of ultraviolet radiation from the sun reaches a maximum; at sunspot minimum, it is at a minimum. In this correlation lies the clue to a large number of terrestrial effects. The biological effects of ultraviolet light might form the subject of a thesis by a biologist. In general, I believe, the thesis would hold that ultraviolet light is conducive of good health; at least, such reasoning has resulted in the fad of sun bathing, either for the acquisition of bodily tone or for the acquisition of a fashionable bodily tan. One might suggest that it is most economical to acquire a coat of tan at times of sunspot maximum, for then the ultraviolet content of sunlight, the motivating factor in the creation of tan, is at a maximum and the desired coat may be acquired in the minimum interval of time.

The influence of ultraviolet light upon plant life is that of stimulating growth, though it must be admitted that frequent rains will also assist the weeds to grow luxuriantly amid the prouder foliage of your garden. If you will grant the earlier theory that rainfall should be at a maximum at the time of sunspot maximum, then the coupling of frequent rains with the maximum receipt of ultraviolet radiation should manifest itself in plant life on the earth. A very simple manner of testing the hypothesis is by the study of the growth of trees. Even as little children we learn that a tree adds a ring each year, so that, by sawing down the old pine tree and counting rings backward from the bark, it is possible to tell its age. The theory would indicate that at times of sunspot maximum the width of the ring should be greater than at times of sunspot minimum or at intermediate times. The correlation is so good that Prof. A. E. Douglass, of the University of Arizona, has used it to determine the antiquity of the Indian ruins in the southwestern areas of the United States, and for carrying back our records of sunspot activity prior to the time of satisfactory man-made records of it. Sample cross-sectional borings of the timbers used in the construction of these dwellings show patterns of ring widths that are reproduced time and again. Comparisons with the cross-sections of recently felled patriarchs of the neighboring wooded areas and correlation with recorded observations of sunspot activity have enabled Professor Douglass to carry back his studies of tree-ring cycles to

the point where it is possible to date the timbers used in these ancient dwellings.

The biological effects of ultraviolet light may be such as to stimulate certain animals to the creation of large litters, which will account for the fact the number of rabbit pelts returned to the wholesalers by the trappers becomes a maximum near the time of sunspot maximum. It is not a case of greater activity on the part of the trappers, but rather a case of more rabbits to be trapped. On the other hand, ultraviolet light is a penetrating radiation that seeps under the cuticle of human beings and stimulates the nervous system, thereby arousing the individual to unusual heights of activity and achievement. With trappers thus excited in their work, it is hardly possible for the cause of their enthusiasm to remain safe; hence the usual number of rabbits may exist, but there is more enthusiastic trapping.

Ultraviolet radiation, as has been previously suggested, is an exciting radiation. That large proportion of it which is not intercepted by trees, plants, and human beings must of necessity find its way into the earth. Whether it can be as exciting of inanimate objects as it appears to be of animate ones is an open question. Yet there seems to be some evidence, perhaps entirely of a coincidental nature, that volcanic activity correlates with sunspot activity. Disturb the under-layers of the earth's crust by an excess dose of ultraviolet radiation and they may find relief by discharging their excess energy as a volcanic eruption.

Already it has been stated that ultraviolet radiation is a stimulant to human beings; it may at the same time be an irritant. A Russian scientist suggested not many years ago, and I have seen the same statement made independently at a more recent time, that great international crises, such as wars, peace treaties, and other evidences of international amity or friction, follow the period of sunspot activity with some fidelity. The basis for such a correlation may be sought in the stimulating effects of ultraviolet light, prodding statesmen to great international concords, or, in its irritating effects, annoying them until they come to blows. The sole difficulty with the correlation and with its theoretical explanation is that the world seems to be in a state of international upheaval at almost any hour in any year.

A correlation of great human interest is that of sunspot activity with stock market transactions and with the price of grain, wheat, cotton, and other major items of exchange, the oft-discovered correlation that prompts such letters as that quoted at the beginning of this article. It is conceivable that the stimulating effects of ultraviolet radiation upon humans should have much to do with the periods of prosperity and depression, and with the flux of prices, not only
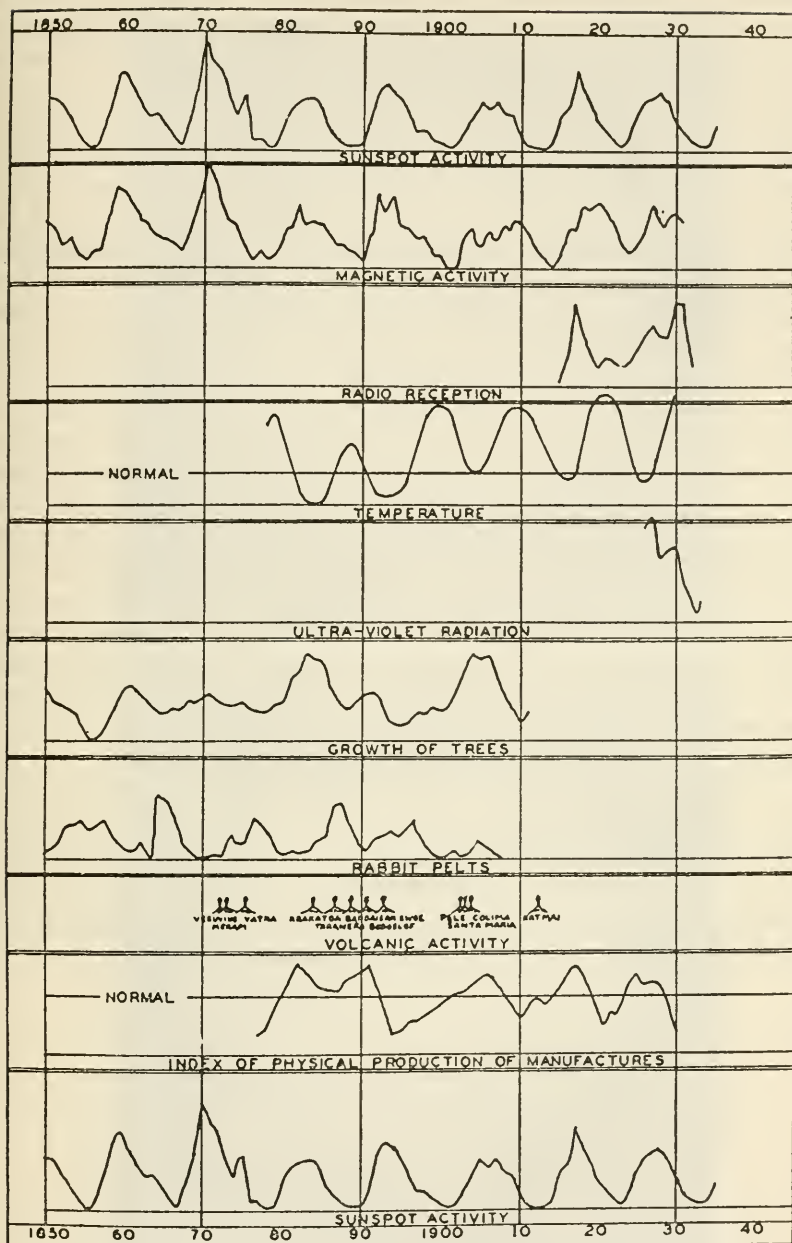
FIGURE 1.—The correlation of various terrestrial phenomena with sunspot activity.

of stocks and bonds, but of staple commodities. Those who bear the brunt of furnishing advice to investors and wholesalers have been enthusiastic in their search for such a correlation between solar activity and terrestrial activity. Needless to say, they have found evidence of such a correlation. As the number of sunspots mounts, prosperity turns the corner; as the number of sunspots diminishes, prosperity hides itself in a depression. It may be pointed out that the last sunspot maximum occurred in 1928, an epoch in the economic history of the United States to which one commonly refers as "the good old days." The last sunspot minimum occurred in 1933. Someone has mentioned an economic depression similarly dated. It is now said that conditions are improving and that prosperity is again just around the corner; sunspots are improving in number as well. The correlation seems amazingly satisfactory, and its amazing properties are enhanced by the fact that it holds equally good over nearly the past two centuries. If you have faith in this relationship, you may heed the advice of the lyrics which runs, "Now's the time to buy, so let's have another cup of coffee and let's have another piece of pie." Whether the lyrical prediction applies also to other fields is left to your own judgment. It would at least seem that all the king's horses and all the king's men cannot bring prosperity back again; but the sun can.

It may justifiably be said that the terrestrial influences of ultra-violet radiation may be expected at times to be immediate, at other times, cumulative. This is shown by the coincidence or lag of the terrestrial curve with respect to the sunspot curve in the accompanying diagram.

The present waxing of sunspots should come to an end in 1939. Concerning some of the concomitant effects we are certain. Concerning the remaining effects your prediction of their trend is as satisfactory as mine. I have laid them before you, here and there in serious fashion, elsewhere with a touch of cynicism. To you is left the final judgment as to when this cynicism is justified.

PLATE 1
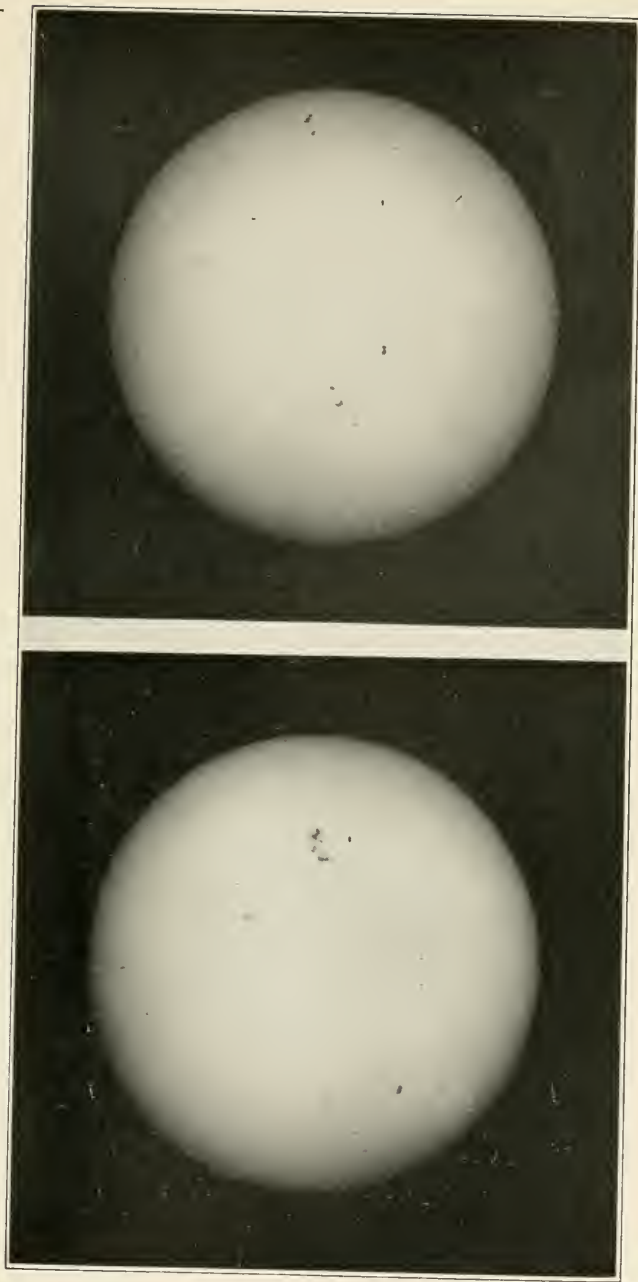
PHOTOGRAPHS OF THE SUN TAKEN AT THE HARVARD ASTRONOMICAL LABORATORY ON NOVEMBER 12 AND 14, 1927.

No. 1. 1926 January 24.

No. 2. 1925 December 28.

No. 4. 1892 February 10.

No. 5. 1917 August 8.

No. 6. 1905 October 21.

No. 7. 1917 February 11.

No. 9. 1920 March 22.

No. 15. 1935 December 2.

Approximate scale.
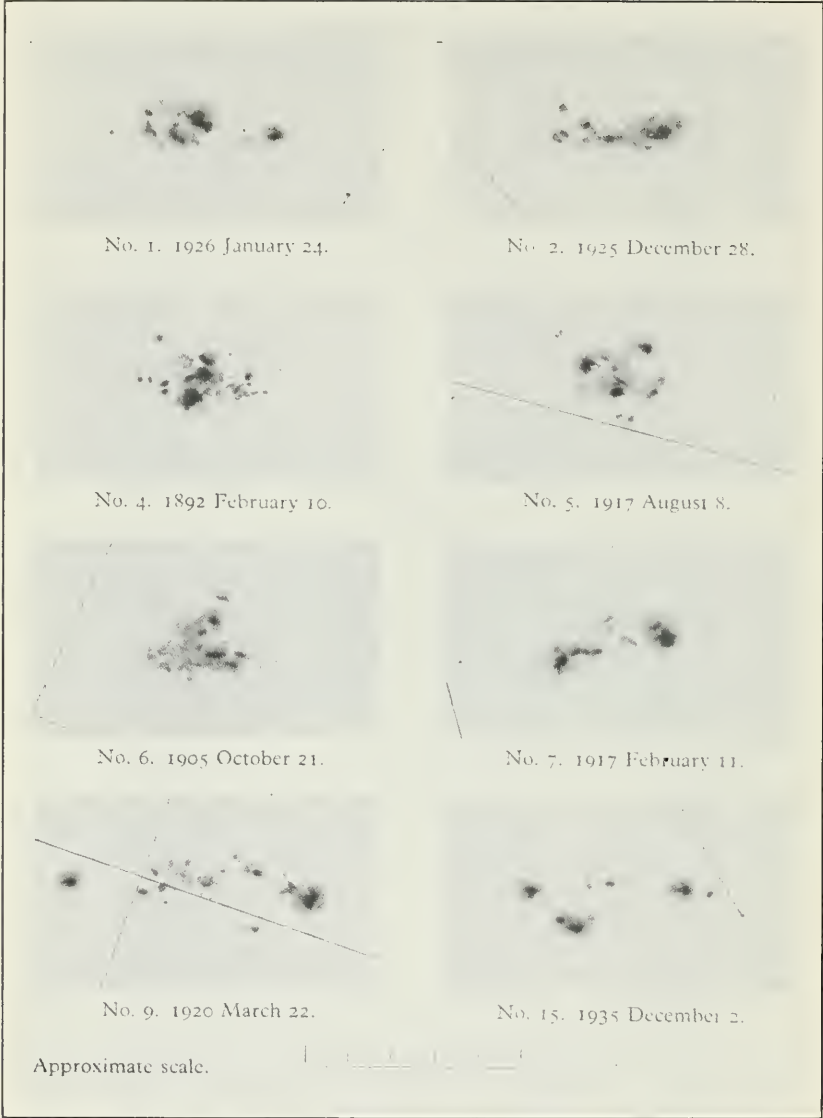
TYPES OF LARGE SUNSPOT GROUPS.

NORTHERN LIGHTS [1]

By A. S. Eve, C. B. E., D. Sc., F. R. S.

Emeritus Professor of Physics, McGill University

[With 5 plates]

THE LOWER AIR

Before considering the upper atmosphere it may be well to recall the remarkable unseen events taking place within this lecture theater of the Royal Institution, so pregnant with famous memories. You probably did not notice that, as the lecturer entered, a large number of an essential part of this gathering went out as quickly as he came in. This number may be estimated at about a million million million million, a number almost sufficient to impress even Sir James Jeans. The calculation is not difficult, for my weight somewhat exceeds that of 2 cubic feet of water. The late Sir Arthur Shipley pointed out that all men, including even the Archbishop of Canterbury, are about 90 percent water, and it is clear that my volume is, more or less as the lawyers say, 2 cubic feet or 5,000 cubic centimeters; but the number of air molecules in a cubic centimeter down here is roughly 2.7 by 10^{19}, a vast number equivalent to 27 followed by 18 noughts. Multiplying these figures together, you obtain more than the million million million million, or 10^{24}, molecules that left the room as each one of you came into the hall. The molecules of air are not at rest but are moving more rapidly than a rifle bullet. They are frequently colliding with one another, each one about 5,000 million times a second, and providing everywhere, by their bombardment, a pressure of 15 pounds to the square inch. If the air in this room, about half a ton of it, could be suddenly removed, my voice could not reach the audience, who would all be dead within 2 minutes, if they had not already exploded outward from their internal pressure of 15 pounds to the square inch. The air molecules are small; about 100 million of them, side by side, would stretch for half an inch or so, but they are by no means crowded, for their average distance apart is 300 times their

diameter. If my audience were similarly dispersed, and if you take your diameter as one foot, then your nearest neighbor would be 100 yards away, so that the audience would be widely scattered and in an extreme state of agitation. The sound waves of the speaker are faithfully transferred to your ears by this wild jumble of swift molecules. There is the further demand of intelligence, the supreme factor in physics, on the part of the audience and the lecturer! In the meantime there are not only a gravitational field and a magnetic field throughout the region, but all the electromagnetic waves, radio or wireless waves, from nearly all the broadcasting stations of the world, are coming through the walls and through our bodies almost as if we did not exist, making the electrons in our conducting bodies dance rhythmically up and down, so that each one of us is an aerial, but most fortunately, I think, we are not gifted with receiving gear to detect this medley. We have to content ourselves with that wonderful octave of electromagnetic waves which gives us the glory of light and the splendor of color.

Do not forget that from the cosmos there come also radiations which can penetrate the whole atmosphere (equivalent to 30 inches of mercury), pass through the roof, through our bodies, very many a second, and plunge down into the earth. As was shown recently in the underground railway at Holborn, even after passing through more than 70 feet of solid ground, there still remains 15 percent of the cosmic rays. On the whole, this theater is a much more lively spot than a casual glance would suggest.

The upper atmosphere consists of air molecules similar to those around us, but, at the reduced pressure of high altitudes, the molecules are much further apart, their free paths are much longer, so that collisions between the molecules are less frequent. The difference between the two elevations cannot be better illustrated than by the passage of electricity between two conducting regions. At our level there is a more or less noisy spark, or a flash of lightning with a peal of thunder. Although it is not possible to go many miles aloft, it is possible to send a current of electricity between two metal electrodes and to observe the changes that take place as the air is pumped from a closed tube of considerable length. On making the experiment there is at first little or no current; the air acts almost as an insulator. On reducing the pressure there is a thin rosy line of light which grows and fills the tube until a considerable current is carried by charged molecules, or ions. It is unnecessary to recall at the present moment all the successive changes, but it will be seen that with a high vacuum a greenish light suffuses the whole tube, because electrons are taking a large share in the proceedings, and you will note that they may be deflected by a magnet.

This experiment is better shown by projecting the electrons through a small hole so that they glance along a fluorescent screen. It is then easily seen that the beam of electrons is readily bent into a circular arc on the approach of a magnet.

Two streams of electrons, passing through neighboring holes, may be seen to repel one another, whereas parallel currents in the same directions, passing along wires, are known to attract. All these preliminary remarks have a direct bearing on the main theme—Northern Lights.

THE UPPER AIR

Dwellers in cities see little of the night sky; they are dazzled by street lights and advertising signs. Those who live in the country enjoy a greater privilege. Although London is nearer to the North Pole than Montreal or Quebec, yet it is the people of Canada who more frequently see the glory of the Northern Lights. It is the distance from the magnetic axis of the earth that counts, and that axis meets the earth about midway between the north magnetic pole and the North Pole. This might be called the north axial pole, and it is near northwestern Greenland.

The appearance of the Northern Lights has been frequently described, and in any case words are quite inadequate to describe its beauty. We must look forward to the time when really good colored motion pictures of the aurora have been taken, and this will be a difficult feat because the light intensity is feeble compared with sunlight. The three main forms of display are the arc or arch, the curtains, and the long streamers. The color is commonly greenish white or greenish yellow, sometimes with an admixture of red or violet. I still remember being taken as a small boy from bed at my home in the Midlands to see from a window the rosy glow of the Northern Lights. It was the winter of 1870–71 when the Prussians were besieging Paris, and the villagers declared that the light was the reflection of Paris on fire, regardless of the fact that Paris was to the south and the lights to the north.

The first appearance of the aurora is sometimes a bright quiescent arch with its peak a few degrees west of due north. This may suddenly be followed with a host of streamers, like searchlights, but changing, flickering, and dancing. This is rather frivolous behavior, for the Eskimo believe that the lights are the spirits of their ancestors. At other times the display begins with nearly vertical curtains of light, the folds of which keep changing in form. It is often a fascinating and resplendent spectacle, and it is pardonable if a word picture falls short of the reality. The drapery is usually to the north, spreading from east to west, but sometimes it appears quite overhead. Even

as far south as the State of New York the curtain may sometimes be seen south of the zenith.

The altitudes of these displays have been skillfully measured in Norway by Størmer, with a number of observers connected by telephone, who took photographs at the same instant from different places at a measured number of miles apart (fig. 1). The photographs (pl. 1) show the Northern Lights in each case with a background of the stars of the Great Bear, but owing to parallax the lights are seen in different positions relative to the stars on the
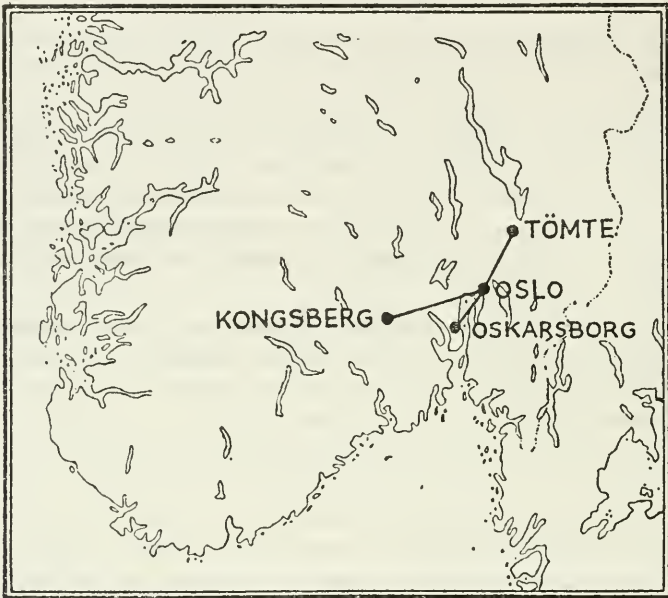
FIGURE 1.—Four stations in Norway selected by Dr. Carl Störmer and connected by telephone. From Oslo to Kongsberg is 63 kilometers.

different photographs. A simple calculation determines the altitude of the aurora. About 60 miles is the most common result, that is, 60 miles from the surface of the earth, not from the observer. Sometimes the tops of the streamers may be 250 miles above the earth, and I believe that the lowest determination is an altitude of 40 miles. The record height for the top of a streamer is 1,000 kilometers, more than 600 miles. Similar measurements were made in Canada by Sir John McLennan and others, and the results there were in excellent agreement with the earlier determinations in Norway.

It is a strange fact, proved by Størmer, that those auroras which have the greatest altitudes, ranging (base to top) from 350 miles to 630 miles, occur in a sunlit portion of the atmosphere far above the

dark region where the observer stands.[2] Those auroras which occur wholly in a dark atmosphere range from 60 miles to 200 miles. Thus the upper ionized atmosphere appears to expand by day and shrink at night. Appleton has found similar results when measuring the altitudes of those ionized reflecting regions which echo back wireless waves of suitable wave length.

Notwithstanding these definite facts, and the further one that Northern Lights appear behind distant mountains, there are many who declare that they have seen an aurora close to the ground. An engineer, with excellent judgment and good observational powers, assured me that he had once seen personally some of his men walk into an aurora! A minister in Canada wrote to me that he was driving a horse and buggy when a brilliant display of aurora appeared near the ground close to his side. He declared that his horse saw it too, for the animal first shied and then bolted. It is no good telling these men that they could see no such thing. A probable but not certain explanation is that a patch of mist close to the ground was lit up by the vivid light of an aurora about 60 miles away.[3]

THE SOUND OF AURORAS

Several observers, some of whom I have met personally, declare that sometimes there occurs with an auroral display a sound, distinctly audible, that resembles the swish of a silk dress, or the noise of a sword moved swiftly with the blade broadside to the air, or of wind whistling in the rigging of a ship. A westerner declared that he was prepared to take an oath (that he could hear the Northern Lights) on a stack of Bibles as high as a church. This picturesque evidence proves nothing, except that the man quite meant what he said. Here is a letter, exactly as written, sent to me by a trapper in the Province of Quebec. Such men live much in the open both by day and by night, and they see much of nature:

Il a été donne ici une conference par un de vos professeurs dont je ne puis me rapeler le nom, le subjet étais les Aurores-Boreales il disait donc que c'est impossible d'entendre le bruit des dit aurores. Je suis trapeur et peut predire la temperature deux à trois jours d'advance par bien des signes quel vous ne connaisser pas et quand des Aurores-Boreales se produisent sa agit sur la temperature c'est par la place ici de dire sur quel cote du temps.

Mais soyez certain aussi que certaine aurore produisent du bruit crepitement faible c'est vrai et aussi comme un bruit de soie qu'une personne froisserait bien à vous.

(Signed) Un Trapeur.

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[2] Science Rev., vol. 1, no. 3, p. 117, Feb. 1936.
[3] See Low Auroras, by G. C. Simpson, Quart. Journ. Roy. Meteor. Soc., vol. 59, pp. 185–193, April 1933.

The following letter was written to me by a McGill engineering student who was fortunate enough to belong to an Arctic expedition which, after so many years of search by so many navigators, did actually discover the North-West Passage:

WESTMOUNT, *February 27, 1931.*

DEAR SIR:

Yesterday evening you were kind enough to request me to write concerning the aurora.

I was fortunate enough to be a member of a Survey Expedition to find the channel through the North-West Passage.

I wintered in the Arctic at the magnetic pole, 70 N., 96 W., during 1928–29. During the period of darkness there were intense displays of aurora, most frequently seen from the SW. to SE. in dead calm weather, temperature 50° F. below zero. In the Arctic silence, it can be definitely said that whistling crackling sounds accompanied the aurora display. They were also seen several times in the NE. Their effect on radio communication was also marked. Most frequently, north and south communication predominated, and only seldom did the east and west predominate. The communication never showed freak reception in all directions at once, but faded on one and increased on the other.

It was difficult to get consistent data of the effects of aurora on radio communication, even though I tested and communicated daily. The same observations were noted from King William Island during 1929–30.

(Signed) H. ROSS SMYTH.

On the other hand, several of my scientific friends, such as Frank Davies, who has been on both Arctic and Antarctic expeditions, have listened in vain for sounds accompanying auroras. Negative evidence, however, is never satisfactory. Others declare that the noise swells and fades at the same instants that the lights increase and diminish in intensity. It is difficult to believe that this could be true. If the aurora is 60 miles away the sound therefrom, if any, would take at 5 seconds for each mile, about 5 minutes to arrive, so that coincidence would be more impossible than between lightning and thunder with a flash many miles away.

Moreover, it must be remembered that sound does not emerge or travel at all well in highly rarefied air such as there is in auroral regions. There is the famous experiment, first made successfully by Robert Boyle, after others had failed, which proved that the sound of a bell does not emerge from within a receiver from which the air is thoroughly pumped. What then do these men hear? It has even been suggested that they hear the blood surging in their head, or the tinkling of the ice of their frozen breath. We may safely dismiss these suggestions as trivial. It seems more probable that they hear something real in the same sense, let us say, that we hear church bells ring. I may venture to suggest that in dry, cold weather there may be a small brush discharge from snow or bushes somewhat similar to St. Elmo's Fire, seen on mountains, and sometimes as an

electric discharge from the masts and rigging of a ship when the earth's voltage differs considerably from that of the air. My verdict for what it is worth, is then, that men cannot possibly hear the Northern Lights, which can make little or no noise, but they may hear something else not far from them, such as a local brush discharge.

SPECTROSCOPIC EVIDENCE

The spectrum of the aurora has been photographed, and most of the lines, or bands rather, are found to be due to nitrogen, which is the major constituent of the atmosphere (about four-fifths) here on earth, and remains the chief constituent at high elevations. The spectrum of the aurora also includes the famous green line which Sir John McLennan investigated so ably, and proved to be due to oxygen in an enhanced or unusual, excited state. He and his coworkers actually produced the green line in his laboratory at Toronto by suitable stimulation of oxygen with helium, neon, or argon also present. About 1 percent of the air at ground level is argon. All the other rare gases are present in much minuter quantities—neon, krypton, xenon, radon. Hydrogen is so light, and the molecular velocity in consequence so large, that the hydrogen overcomes gravity and passes out of the atmosphere.

Some of these gases, notably neon, the ingenious Claude has shown us how to collect, to place in tubes at low pressure, and to ionize with high voltage, so that every city is besplangled with artificial auroras, and decorated with an extraordinary variety of colored signs and vivid advertisements. The question is whether we most admire their scientific interest, their intrinsic beauty, or the subtle skill with which they invite or induce the public to buy. It was supposed that some of the rare gases played a part in the rich coloring of auroras, and McLennan suggested that at high altitudes there is more helium than oxygen. On the other hand, experiments by Kaplan indicate that enhanced nitrogen can also stimulate oxygen to emit the light of the green line. Furthermore, the extended researches of Vegard show that the spectra of auroras contain lines or bands of nitrogen and oxygen only. No traces of hydrogen or helium were found.

THE AURORA AND MAGNETISM

Everyone today is familiar with a magnetic field, particularly as everyone has lived all his life in a feeble field of that character due to our great magnet the earth. It is not suggested that we know exactly what magnetism is, but then that is true of everything else. The magnetic compass needle, in some form or other, can reveal to us both the direction and intensity of this field at any desired point. Most people also know something of the behavior and properties of

electrons, and perhaps it is fair to add that the younger they are, within reason, the more they know about them. The older among us are conscious that this omniscience of the younger is not wholly confined to electrons. However that may be, it is certain that if you shoot electrons at right angles to a uniform magnetic field, the electrons will go round in circles—exact circles. The stronger the field and the slower the electrons, the smaller will be the circles, and the converse is true. The mathematical, electrical, and mechanical principles are simple and certain. People are beginning to believe that physics is becoming indefinite and hazy, because they attend to the fascinating borderlands of speculative science and are forgetful of the definite and eternal verities. If, on the other hand, electrons are projected obliquely to a magnetic field then the electrons will each one describe a helix or a path with the shape of a corkscrew.

If electrons are shot earthward from the sun, they will travel through space and become entrapped by the magnetic field of the earth. They will spiral round the lines of force until they meet the upper atmosphere in the regions surrounding either the north or south magnetic poles. The speed of such electrons may be sufficient by their collisions to ionize the molecules, that is, to knock other electrons from them, thus leaving positively charged molecules, or ions. The recombination of electrons with positive ions is attended with radiation, as has been amply proved in laboratory experiments. It is generally believed that electrons spiraling round in one direction arrive near the north magnetic pole and give rise by ionization to the aurora borealis; while similar electrons spiraling round the lines of magnetic force in the other sense proceed toward the south magnetic pole and occasion the aurora australis. This result is well confirmed by experiment. In spite of some effort, I have not yet been able to discover whether major displays of northern and southern lights occur together at the same time in both Arctic and Antarctic regions. There are some theoretical reasons for expecting such coincidence, and some of the major displays, such as that of February 4, 1872, have been seen in both northern and southern latitudes.

There are some authorities who declare that light charged particles such as electrons would mutually repel one another on their long journey from the sun, so that they would be scattered far afield and in that case there should be no auroras at all! Prof. S. Chapman states that there are positive, negative, and neutral particles all coming from the sun. There is a very wide choice of possible projectiles—electrons, positrons, protons, neutrons, deutons, alpha particles, and cosmic rays, besides photons. Therefore it is not wise to be too dogmatic as to the nature of the bombardment that arrives at the earth's surface, but it is right to insist that only electrically

charged particles will show so marked a tendency to proceed toward the two main magnetic poles of the earth.

It may very well be asked why it is claimed that the projectiles come from the sun. The answer is that auroras, sunspots, and magnetic storms all follow, over a long series of years, the same periodic variation of increase and decrease in number and intensity. This is the well-known 11-year cycle. In recent years the variation of the effective frequency required for radio signals across the Atlantic has been found to follow the same cycle. The general result is that we have a twofold aspect of the sun. On the one hand, it must be regarded as a variable star with an 11-year period. On the other hand, it is endowed with such marvelous constancy that the main temperature of the earth has continued between the freezing and boiling point of water ever since life first appeared upon the earth many hundreds of millions of years ago, with every prospect of its long continuance. The sun converts some of its mass into radiation at the rate of 3 or 4 million tons a second, and yet plenty remains. This delicate balance of temperature must be an unusual feat, and is a thing which, if it had not happened, would be deemed impossible. In my young days Sir George Stokes would have said, "Design!" Today many say, "Chance!" Looking on the matter as fairly as I can, and not attaching too much weight to my enormous veneration of Stokes, it still seems to me that he was probably correct. This is a difficult question which everyone must decide for himself, unless he prefers to sit on the fence.

AURORA AND THE WEATHER

There is a popular belief that a change of weather follows the Northern Lights—a change for the worse. There are many beliefs also connecting the moon and the weather; for if the moon is linked with the tides, why not with the weather? A glance at a large scale map will show that many various types of weather, good, bad, and indifferent occur at any and the same time, at different places on the whole face of the earth, whereas the phase of the moon is the same for all. A somewhat similar statement may be made about an auroral display, which often covers a large region and has to be responsible for varied conditions. Besides, the aurora is 50 to 60 miles high, and our weather is brewed in the lowest 10 miles, for the very highest cirrus clouds are rarely higher than 6 miles. There is, however, this point to be remembered: Northern Lights are not seen in cloudy weather, but only in clear. Hence it is much more probable that rain or cloud will follow the aurora than the reverse, but it is probably erroneous to state that the change was caused by the aurora.

EXPLORING THE UPPER ATMOSPHERE

Today there are eight different ways of obtaining information about the nature and properties of the upper air (fig. 2).

Pilot balloons filled with hydrogen can carry up small, light, ingenious recording devices. If the balloon is recovered on its
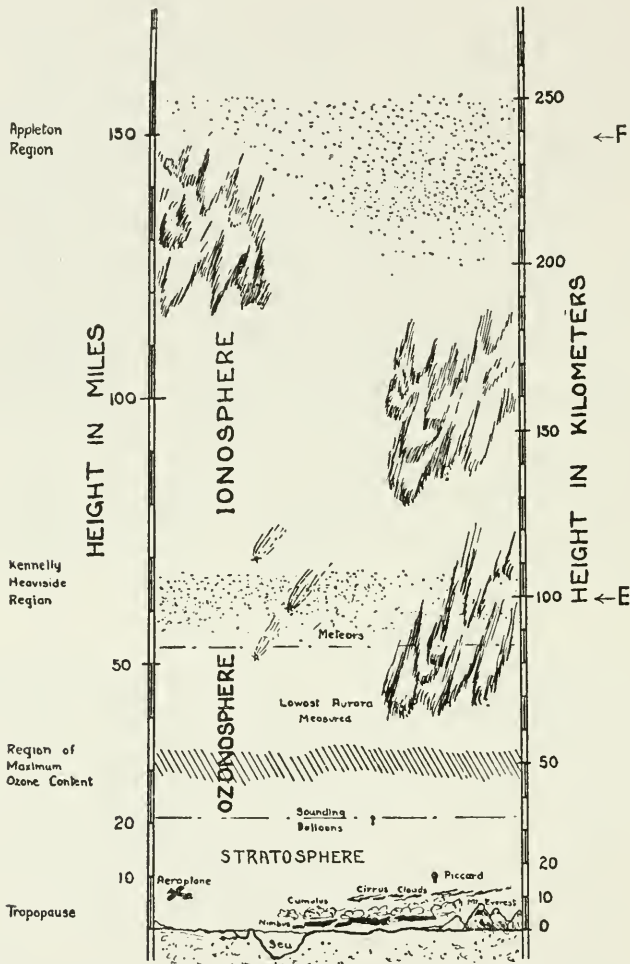
FIGURE 2.—The atmosphere. The diagram indicates the heights of mountains, Piccard's gondola balloon, sounding balloons, the ozone region, meteors, northern lights, and the two main regions (E and F) capable of reflecting radio waves. (From Physics, by A. S. Eve. Thornton Butterworth, Ltd., London.)

return to earth, there are records of elevation, temperature, and humidity. Such balloons may also be followed with a transit instrument, or theodolite, so that the wind velocity at different levels may be deduced. The greatest elevation attained by a balloon without

recorders, was 23½ miles, at Padua. One of Regener's balloons has ascended 17½ miles and been recovered with its recorders.

In recent years attempts have been made to explore the stratosphere in balloons. The intrepid Piccard constructed a gondola sufficiently strong not to explode outward, and was himself carried inside it upward by a balloon. The ascent is easy, the place and nature of arrival on the earth are largely fortuitous. He reached an altitude of 10 miles and obtained valuable results on the cosmic rays, which at that height are about 100 times as intense as on the earth's surface. The Soviet gondola crashed to disaster after attaining an altitude of 12 miles. The greatest height so far attained is 13½ miles, achieved last year by Anderson and Stevens in the United States.

A new method of exploration has recently been devised by Tuve and others, members of the Department of Terrestrial Magnetism, Carnegie Institution of Washington. A searchlight beam is directed upward to a height of 17 to 40 miles, and the intensity of the light is modulated, or varied periodically at the source. A large concave mirror collects the scattered light from the upper part of the beam and brings it to a focus on a photocell connected to an amplifier, which is synchronized with the modulation of the searchlight. This apparatus may well give some information on the nature of the molecules in those very regions on which we are least informed, above the range of pilot balloons and below the auroral and ozone layers.

Ozone, O_3, is produced from oxygen, O_2, by radiations of a suitable frequency or by electrical discharges. Much of the ultraviolet light from the sun is absorbed or stopped in the ozonosphere about 20 to 40 miles above the earth. The presence of the ozone is revealed by absorption bands in the spectrum of the sun. When the sun is high it passes almost vertically through the ozone layers. When the sun is setting its rays have to pass horizontally through a much greater thickness. Measurements of the intensities of the absorption lines due to ozone lead to an estimate of the height of the ozone region as being about 25 miles, and therefore lower than the Northern Lights.

The barometric disturbance due to the great Krakatoa volcanic explosion traveled four times round the earth, and the actual noise of it was heard 3,000 miles away. The sound of big guns or of heavy explosions passes upward into the cool and rarefied air and is then refracted or bent back again to the earth, so that sometimes, like short-wave radio, it cannot be heard or detected at intermediate distances. Newton stood in the gateway of Trinity College, Cambridge, and heard the guns of the naval action between the Dutch

and the English. He foretold a British victory, because the noise of battle became gradually fainter as the victors pursued the Dutch. The fact that sounds are bent back again to the earth necessitates a warmer layer above the cold. It seems that with increasing altitude the temperature may gradually decrease down to many degrees below zero Fahrenheit, but at a height of 30 miles there is an increase up to 80° F., and the heat to maintain this may be connected with the formation of ozone from oxygen by the sun's ultraviolet light.

RADIO WAVES

The most important method of throwing light on the nature of the upper regions of the air is by projecting radio (or wireless) waves directly upward, for it is found that with suitable frequencies they will be reflected back to the earth. It will be recalled how puzzling it was, in the early days of wireless, to account for the fact that the electromagnetic waves, expected to move in a straight line like light, could travel from Ireland to Newfoundland. Today wireless waves, carrying speech, music, or Morse, can be sent completely round the world, so that a man can speak to himself and hear it a fraction of a second later, using waves which have circumnavigated the globe, changing local time in the most remarkable way as they traveled. During a part of the journey it must have been yesterday, or tomorrow though on return it was the same day and perhaps about a seventh of a second since they started. It was surmised both by Kennelly and by Heaviside, independently, that the possibility of successful long-range wireless signals depended upon reflection or refraction by an electrified or ionized region at a considerable height above the earth. The proof of the existence of such a conducting region was given by Appleton, who also showed that there is another higher region also capable of reflecting radio waves back to the earth.

The lower or E region is at about 100 kilometers, or 60 miles from the earth, and it is also called the Kennelly-Heaviside region. The upper or F region is two or three times as high, and bears the name of Appleton. It is possible to send a brief signal of suitable frequency which will be reflected back from both the E and F regions, so that both signals may be recorded on a suitable photographic plate (pl. 2) by means of a cathode ray oscillograph. It is possible to measure the very short period of time between the initial and return signals, and, as the velocity of such waves is about 186,000 miles a second, it is easy to deduce the height of the reflecting region. For example, if the interval is one-thousandth of a second, the reflecting layer would be about 93 miles above the earth. Experiments carried out by Henderson and others, during a total eclipse of the sun in

Canada, proved that the E region is made conducting, or is ionized by the ultraviolet light from the sun, but it is not yet possible to assign a cause to the F region.

It should be clear now that it is necessary to determine in due course the different types of radiation responsible for (a) the ozone layer, (b) the Kennelly-Heaviside layer, (c) the Appleton layer, (d) the more occasional and local auroral displays, all of which are attributable to the sun's activity. There is a yet more difficult problem with respect to the cosmic rays and the bursts or showers of ions to which they give rise. Sometimes a hundred million ions occur at a single outburst.

In the upper atmosphere the pressure is so low that the molecules are quite far apart, and if an electron is detached from a molecule by some type of radiation, it may have to wander a long way before it can find a partner in a positive ion; or it may find a resting place on a neutral molecule, so that the pair become a negative ion. While free, the electrons are so small and light compared with their electric charge that they are readily made to oscillate, or dance in rhythm, with any electromagnetic waves that are passing them. Curiously enough, the group of waves travels the faster in consequence, so that an electromagnetic wave entering these ionized regions obliquely has the upper part wheeling faster than the lower, until the wave front is turned round and proceeds downward to the earth again. However, much the same sort of thing happens every time you look into an ordinary mirror or looking glass. There also the free electrons in the mercury at the back of the glass are able by their stimulated motion to return to you a fairly faithful image of your face.

Radio signals will also bounce to and fro between the earth and the reflecting regions, proving that the earth also is an admirable radio reflector. The total path for eight such reflections, which have been obtained from the F region, must exceed 2,000 miles.

SUNSPOTS

In the old days the heavens were deemed to be eternal, changeless, and perfect, so that the discovery in the days of Galileo that there were spots on the sun came as a shock to medieval thought. The face of the sun is a turbulent place at the high temperature of 6,000° C. Black spots appear on it, sometimes large enough to be seen through a darkened glass with the unaided eye, and much broader than the diameter of the earth. The number of these spots follows the same 11-year cycle as the frequency of the aurora. At the beginning of such a period the face of the sun may be practically without spots (pl. 3). In due course a few appear in middle latitudes on both sides of the sun's equator. There is a steady increase in number, the spots
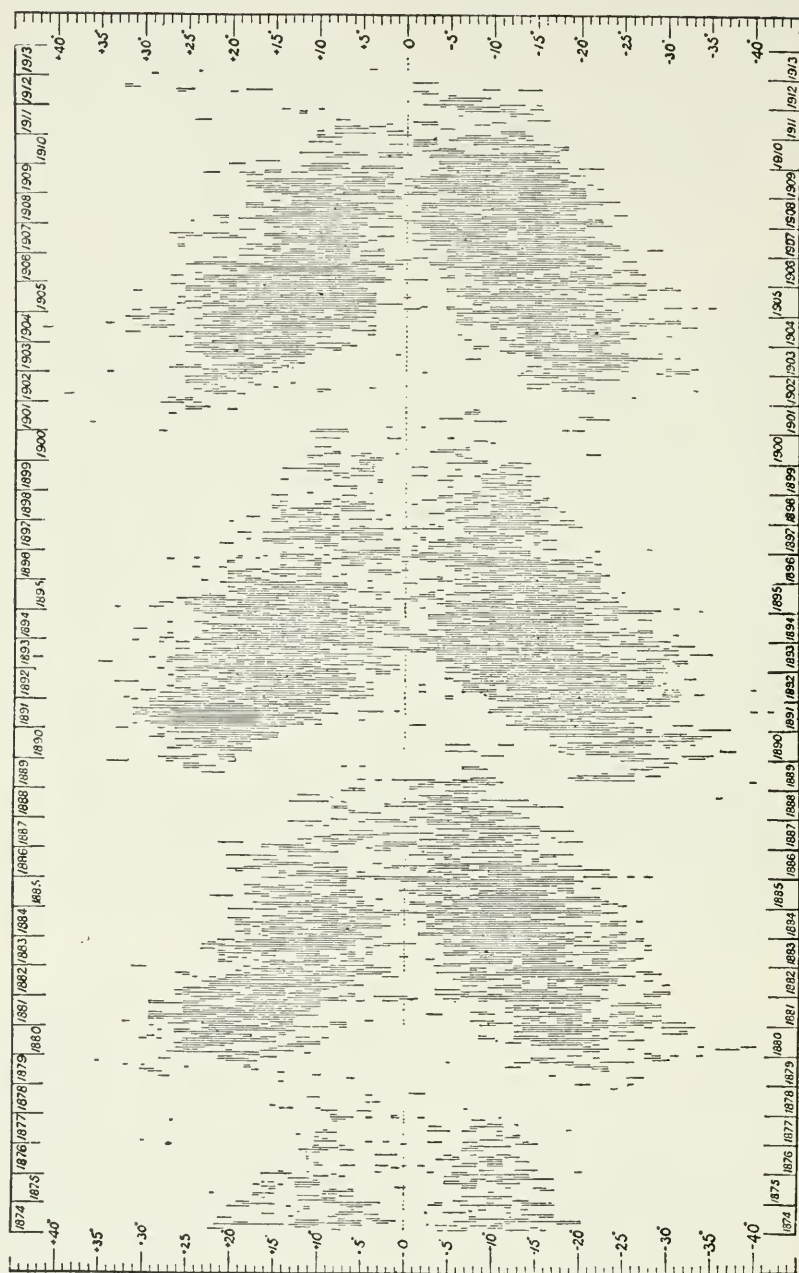
FIGURE 3.—Distribution of spot-centers in heliographic latitude.

become nearer to the equator, and they disappear when at the lowest attained latitudes.

These relatively cool, dark whirlpools reveal magnetic properties discovered by Hale through the Zeeman effect, and they may perhaps be compared with the "lows" or cyclones which so often bring storm, rain, and flood. The periodicity of sunspots, auroras, magnetic storms on the earth, and changing radio phenomena has been found to hold good for the fluctuations of the white polar caps on the planet Mars and even for a cycle of ring growths in the great and ancient trees of western America.

METEORS

Most people are familiar with shooting stars or meteors and many have seen in their lives dozens or hundreds of them; yet it always comes as a surprise to learn that no less than 20 million of them every day plunge into our atmosphere with velocities ranging up to 130 miles a second. Sometimes these visitors are but the size of a pin's head, and at other times they are large enough to pierce the atmosphere and reach the earth. The famous Arizona crater may have been formed long ago by a giant meteor; the crater is 1,400 yards wide and more than 500 feet deep. In 1908, a great meteor, estimated to weigh 130 tons, fell in Siberia and devastated by its great heat hundreds of square miles of country. The elevation of most frequent meteoric displays is about 40-60 miles above the earth. It is somewhere in this region that the temperature rises according to the theory of the reflection of sound waves, to which already reference has been made. Sometimes the meteors are of iron, sometimes of stone, and it is not easy to understand how they become red or white hot when rushing through cool air, how indeed they acquire more heat from the bombardment of molecules than is carried away by them. However, the luminosity of meteors occurs in rarefied air at heights of 100 to 30 miles above the earth. An experiment in the laboratory of a similar character would be difficult to make, because our projectiles achieve a speed of a few thousand feet a second as contrasted with meteors having velocities of many miles a second.

MOTHER-OF-PEARL AND NOCTILUCENT CLOUDS

There occur rarely and at great elevations iridescent clouds, as remarkable for their beauty as for their height. They are generally observed over regions of low barometric pressure and it is probable that the clouds are formed of supercooled water vapor.[4] Størmer and his coworkers have measured the altitudes of many of these

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[4] S. Chapman, Nature, vol. 129, p. 497, Apr. 2, 1932.

"mother-of-pearl" clouds (pl. 4) and found them to be in the strato-sphere, about 15 miles above the ground.

The strangest of clouds (pl. 5) are those observed in the middle of the night, or twilight, which occur at a measured altitude of 50 miles. The heights have been measured in Norway [5] by the same band of observers and at many of the same stations as those used in the determinations of the distance of auroras from the earth's surface. These clouds are not iridescent, and they move westward at about 100 miles an hour.

It will be gathered that the study of the Northern Lights is bound up with other physical phenomena in the upper regions of our atmosphere, and that progress can best be made, as in other branches of science, by advance on a broad front.

[5] Carl Størmer, Astrophysica Norvegica, vol. 1, no. 3, February 1935.

PLATE 1
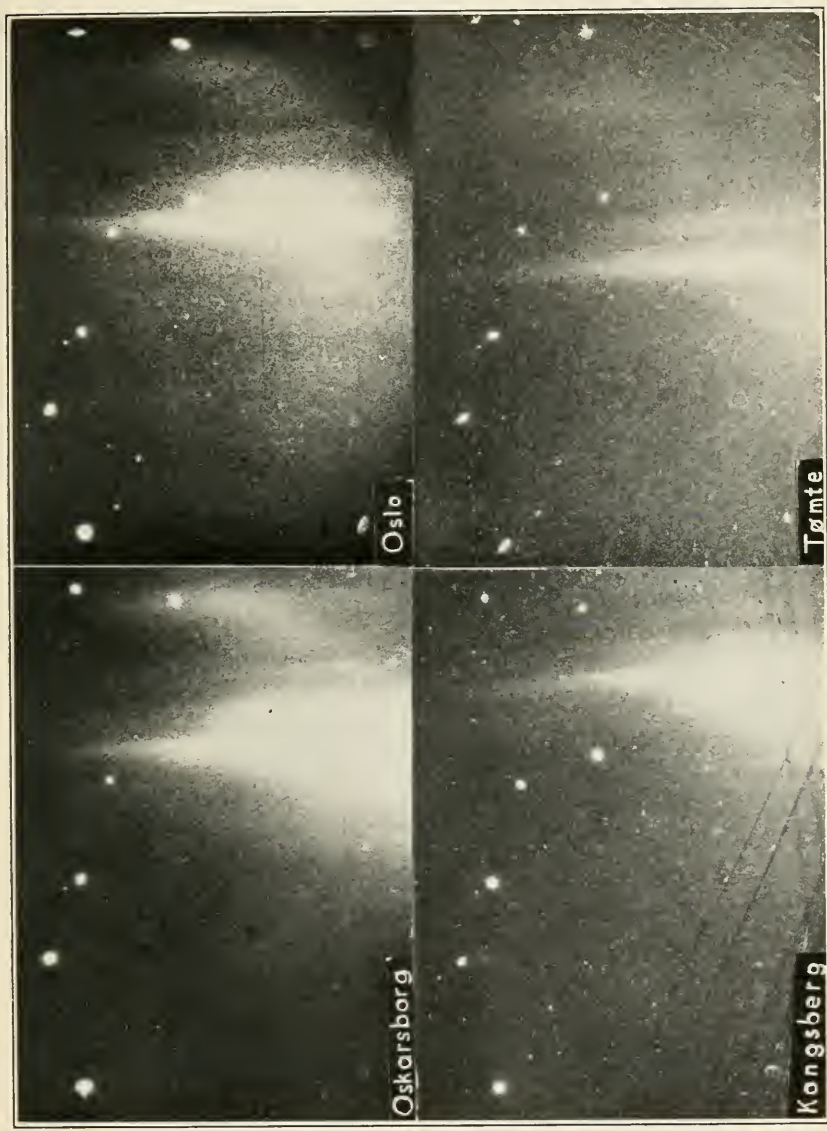
PHOTOGRAPHS OF AN AURORA TAKEN AT THE SAME INSTANT FROM THE FOUR STATIONS, WITH THE STARS OF URSA MAJOR IN THE BACKGROUND.

This aurora was partly in sunlight, and of unusual height. Altitudes: To base, 200 miles; to summit, 375 miles; sunlight above 190 miles, darkness below.
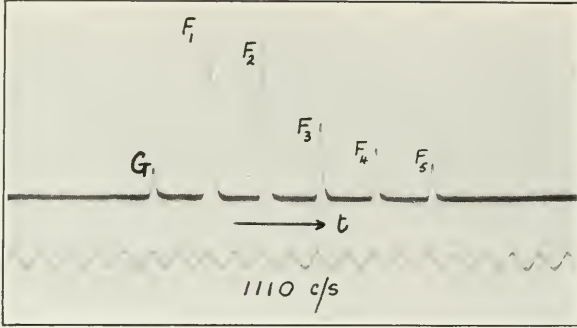
1. REFLECTIONS OF RADIO WAVES FROM THE APPLETON OR F REGION.

G is the ground or original signal. F_1, F_2, F_3 . . . are successive signals echoed from the stated region or after repeated reflections from ground and ceiling.
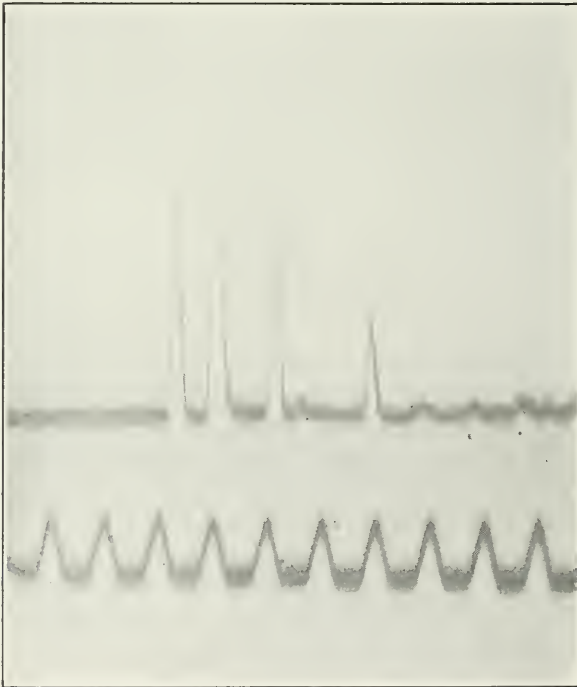
2. THERE ARE ECHOES SHOWN FROM BOTH E AND F REGIONS.

The lower curve gives a time-scale of 1,110 cycles a second. Figs. 1 and 2 are due to the courtesy of Prof. E. V. Appleton.

PLATE 3
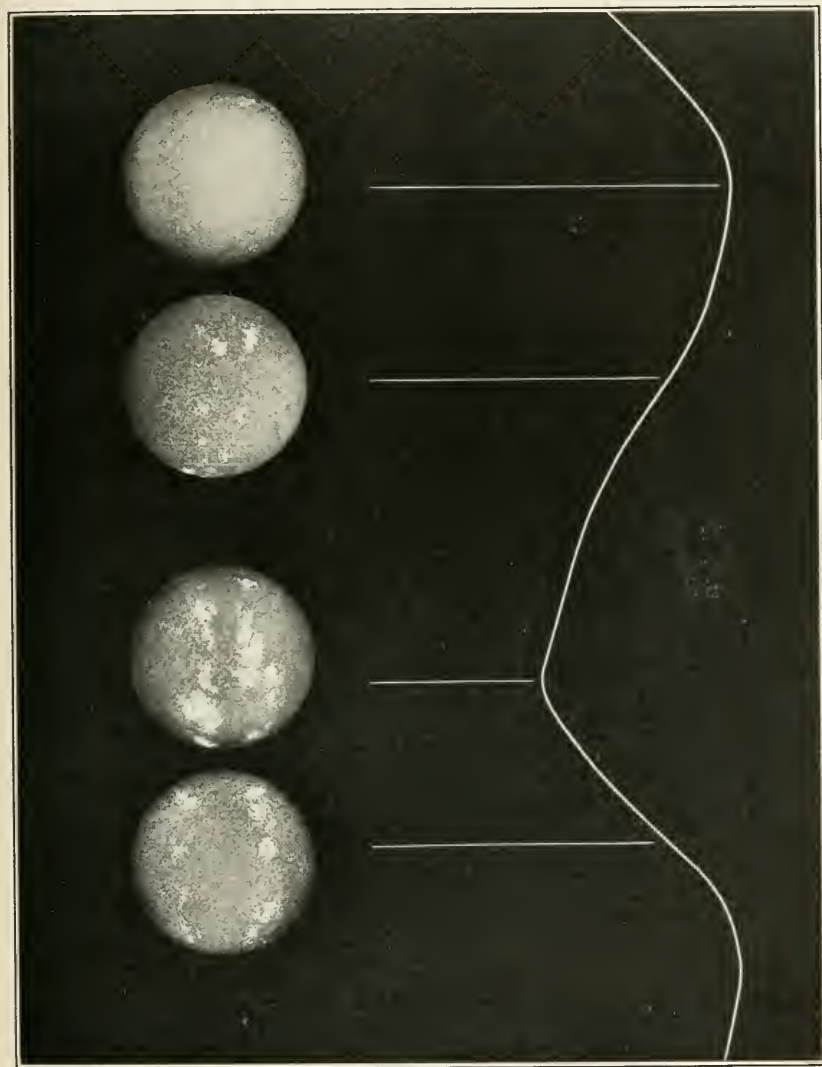
FOUR STAGES OF THE SOLAR ACTIVITY, TAKEN IN CALCIUM LIGHT AT MOUNT WILSON OBSERVATORY.

(Eleven-year cycle, from left to right.—First quarter, full, waning, clear.)

PLATE 4

Dr. Carl Størmer.

MOTHER-OF-PEARL CLOUD, ABOUT 15 MILES HIGH.

Norway, January 29, 1932.

PLATE 5

Dr. Carl Störmer.

LUMINOUS NIGHT CLOUDS. ALTITUDE, 50 MILES.

Photographed at Drøbak, south of Oslo, midnight, July 27–28, 1909.

RADIOACTIVITY AND ATOMIC THEORY [1]

By Lord Rutherford, O. M., F. R. S.

Nearly 40 years have passed since the spontaneous radioactivity of uranium was shown by Becquerel in 1896. We know that the investigations which led to this fundamental discovery were much influenced by the discovery of X-rays by Roentgen in the preceding year. We can now look back with some sense of perspective and recognize the extraordinary importance of the discovery of radioactivity and the profound influence on our knowledge of atoms and the relation of the elements which has followed from a detailed study of the radioactive bodies.

In the course of this lecture, I have thought it of interest to give a brief account of some of the earlier experiments in radioactivity which pointed the way to the conclusion that the radioactive bodies were undergoing spontaneous transformation. This will be followed by a statement of the most significant of the discoveries that have resulted from an examination of the chemical and radioactive properties of the radio-elements. But this in a sense is only the beginning of the story. The use of swift α-particles to bombard matter gave us the first proof that certain light elements could be transformed by artificial methods. This has been followed in recent years by experiments in which streams of other fast particles, like protons, neutrons, and deuterons, have been artificially generated in order to bombard matter. By these methods, we have been enabled to extend widely our knowledge of the modes of transformation of the elements. In some cases, the nuclei of the atoms can be caused to break up with explosive violence, giving rise to new stable elements. In other cases, new radioactive bodies are produced which correspond to unstable isotopes of the elements. More than 50 of these artificially produced radioactive bodies are now known, and no doubt many more will be found in the near future.

The subject of radioactivity has indeed been born anew and has entered again on a new and vigorous phase of life. It is of interest

to note that the methods developed long ago for the investigation of the radioactive bodies proper are now every day being applied to study the artificial transformation of elements and to follow the chemical changes involved. I have personally followed with great interest this ever-widening extension of the province of radioactivity, which today embraces so many workers and has already given us a new science in which the reactions occurring in the minute nucleus of an atom can be studied. The opening up of this new territory has only been made possible by the development of new and powerful electric methods of producing intense streams of bombarding particles with high speeds, and by the improvement of the automatic methods of counting swift particles, and by the wide use of that wonderful instrument, the Wilson expansion chamber, to obtain visual evidence of the process of transformation.

Before discussing the changes in our ideas due to the study of radioactive transformations, we may pause for a moment to consider the prevailing ideas on atoms and their structure just before the discovery of radioactivity (1896) and the proof of the independent existence of the electron (1897). The atomic theory of Dalton had been almost universally accepted as the basis of the interpretation of the facts of chemistry. The work of the chemist for nearly a century had resolved our material world into 80 or more distinct types of atoms or elements, and had shown that the atoms of the elements were stable entities unchangeable by the chemical and physical forces then at our disposal. With increase of knowledge, the old ideas of the alchemists of the transmutation of the elements had been discarded, although it was recognized that one of the main problems of chemistry was to disclose the true relation of the elements and if possible to devise more potent methods capable of changing one element into another. This was well expressed by Faraday, "to decompose the metals, then, to reform them, to change them from one to another, and to realize the once absurd notion of transmutation, are the problems now given to the chemist for solution." To the philosophic mind, the periodic law of Mendeléef was of great significance in indicating that the atoms of the elements were not separate creations but closely related in their ultimate structure, but there was at that time no clue to the underlying meaning of this remarkable relation. It should be recalled that the periodic classification had been successful in predicting the properties of missing elements, and, indeed, the position of several elements discovered later, after Moseley's generalization, had been indicated correctly.

While the law of combining proportions did not involve any definite knowledge of the size and structure of atoms, yet the size and weight of the individual atoms had been roughly estimated from

data based on the kinetic theory of gases. There was, however, little definite information to form any idea of the structure of atoms, although theoretical physicists like Larmor and Lorentz, in order to account for the vibrating properties of the atom as shown by its line spectrum, had suggested that the atom must consist of charged particles, but there was no evidence of the nature of the particles concerned. This difficulty, as we now know, was in part resolved by the discovery of the electron and the interpretation of the Zeeman effect. At this stage, although the relative atomic weights of many of the elements had been accurately measured, the ideas of atoms were very vague and uncertain. Although an enormous amount of information on the combining properties of atoms had been collected, and simple and useful working rules had been applied in explanation, more definite ideas of the underlying meaning of chemical combination had to await a much clearer conception of the electronic structure of atoms.

EARLY EXPERIMENTS IN RADIOACTIVITY

My introduction to the subject of radioactivity began in a natural way in the Cavendish Laboratory, Cambridge, in 1897 as the result of earlier experiments on the ionization produced in gases by X-rays. Becquerel had shown that the radiation from uranium caused the discharge of an electroscope, but had concluded that the radiation was different from X-rays in showing some evidences of refraction and polarization. I proceeded to examine whether the ionization was of the same type as that produced by X-rays and in the course of the work found that the rays were of two types, one easily absorbed, called the α-rays, and a more penetrating type, named the β-rays. A few observations were also made on the rays from thorium, which Schmidt in 1898 had found to be radioactive. Soon after my appointment to McGill University, Montreal, in 1898, Prof. R. B. Owens and I began some experiments on the radiations from thorium, using the electrical method. We found that the effects produced by some thorium compounds, and particularly the oxide, appeared to be very capricious and much influenced by slight draughts of air in the testing vessel. Strong ionizing effects were observed when thoria was covered with several sheets of paper, but only weak effects when the preparation was completely covered over by a thin sheet of mica. This peculiar inconsistency of the effects from thorium was at first very puzzling, as under the same conditions the radioactivity shown by uranium was quite constant.

In order to investigate the matter further, I arranged to pass a current of air over the thoria down a long tube and to examine the conductivity of the air in a large ionization chamber by means of

an electrometer. I then found that, on stopping the current of air, the ionization effect fell off according to a geometrical law with the time, diminishing to half-value in about 1 minute. It thus seemed clear that thoria emitted some kind of active substance which was carried away with the air stream and decayed in activity with time. I gave the name "emanation" to this unknown substance which readily diffused through paper. This was the first time that the characteristic law of decay of radioactive bodies had been measured. At the same time, I noticed that all substances which came in contact with the emanation for some time became radioactive. This "excited" activity, as it was unfortunately termed, decayed with time after the removal of the emanation, according to the same law as the emanation but with a much longer half period, viz., 11 hours instead of 1 minute. Another surprising result was observed in a strong electric field. The activity was to a large extent concentrated on the negative electrode. In this way, a platinum wire could be made strongly active. The activity on the wire could be driven off by heat and removed by solution in acids, but when the acid was evaporated, the activity remained behind. These results were a strong indication that the activity was due to some kind of matter produced either from the emanation or by its action. It seemed likely that the emanation existed in very minute quantity, but it occurred to me that diffusion methods might throw light on whether the emanation was a light or a heavy substance. For this purpose, the relatively long-lived emanation from radium was employed. By measuring the coefficient of diffusion of the emanation into air, Miss H. T. Brooks and I concluded that its molecular weight was large and of the order of 100.

About this time, 1901, began that fruitful association with F. Soddy, who was then a teacher in the Chemical Department of McGill University. At this stage, the subject of radioactivity was in a very confused state. A number of substances had been found to show a temporary activity when separated from a radioactive solution or exposed to radioactive bodies, and the idea had arisen that the radiations had in some way the property of "inducing" radioactivity on bodies exposed to the radiation. This was a natural but mistaken idea which had to be cleared away before progress could be made. For this purpose we first made experiments on the thorium emanation to determine its chemical properties and to find whether it originated from thorium itself or from some other substance associated with it. We found that a new radioactive substance, named thorium-X, could be chemically separated from thorium and that this substance and not the thorium itself gave rise to the emanation. It was found that thorium-X was being produced

at a constant rate in the thorium and was converted into emanation. The constant activity due to thorium-X was shown to be the result of an equilibrium process in which the decay of the active matter was balanced by its continuous production. This process of production and decay was found to be a universal property of the radioactive bodies.

A study of the chemical properties showed that the emanation of both thorium and radium must be chemically inert and correspond to the group of gases of the helium-argon family. We now know that the radioactive emanations are isotopic representatives of the last of the inert gases. Finally, the material nature of the emanations was definitely established by proving they could be condensed in a spiral surrounded by liquid air. It is a noteworthy example of the delicacy and certainty of the methods of detection of radioactive matter that the chemical nature of the emanations and their condensation at low temperatures could be definitely established with almost infinitesimal amounts of active matter, far too small to be seen or weighed or detected by the spectroscope.

The experiments with thorium-X and the emanation gave us for the first time a clear idea of radioactive processes and led us to put forward in 1902–03 the transformation theory of radioactive elements. Although the results were substantiated and extended by investigations with other radioactive substances, time does not allow me to refer to them, and I must pass on at once to consider the importance of these new ideas on transformation.

THE TRANSFORMATION OF RADIO-ELEMENTS

The proofs that radioactivity was a sign and measure of the instability of atoms and that the radio-elements were undergoing spontaneous transmutation were contributions to our knowledge of outstanding importance. The long series of radioactive changes in uranium, thorium, and actinium were with few exceptions made clear during the next few years. There were thus brought to light more than 30 radio-elements, each of which showed distinctive radioactive behavior and broke up according to a simple and definite law. In most cases, in the process of transformation, the radio-element emitted either a swift α-particle, now known to be a charged atom of helium, or a fast β-particle (negative electron). The transformation process is distinguished from an ordinary chemical reaction, not only because the disintegration appears to be spontaneous and unalterable by the forces at our command, but, most important of all, by the enormous amount of energy emitted from each exploding atom. This energy is for the most part emitted in the kinetic form of a swift α- or β-particle, but in some cases a part of the energy is emitted in

the form of electromagnetic radiation of high frequency (γ-rays). Since there was a large emission of energy in the change of one atom into another, it was natural to infer that a large store of energy was contained in a heavy atom. It was clear, too, that the atom must be the seat of intense internal forces in order to be able to hurl out a fragment of itself with such high speed.

Since experiments are usually made with small quantities of active matter or with elements like radium of slow rate of transformation, it is not easy to realize except in imagination the extraordinary effects that would be observed if we could, for example, experiment with a reasonable quantity of a short-lived element like the gas radon. Suppose we were able to obtain a kilogram of this gas and introduce it into a bomb made of heat-resisting material. At the end of about 2 hours heat would be evolved corresponding to about 20,000 kilowatts, and the bomb would be melted unless it were very efficiently cooled. Penetrating γ-rays would be emitted with energy corresponding to about 1,000 kilowatts. The heating effect would die away with the decay of radon (half period 3.8 days). At the end of about 2 months the radon would mostly have disappeared, but in its place would remain about 54 grams of the gas helium, and deposited on the walls 946 grams of a lead isotope (radium-D, atomic weight 210), mixed with a small quantity of radium-E and polonium. After allowing about 200 years for most of the radium-D to disappear, we should then find remaining about 72 grams of helium and 928 grams of an inactive lead isotope of atomic weight 206. I cannot imagine a more convincing experiment to illustrate the striking nature of these radioactive transformations, but unfortunately, or rather fortunately having regard to the safety of the investigator from the radiations, there is little chance of trying such a large-scale experiment.

The property of radioactivity, apart from uranium and thorium and their products, is shown only by a few other elements, potassium and rubidium—to which may now be added samarium—and then only to a very feeble degree. All the rest of the chemical elements appear to be permanently stable when tested by the criterion of radioactivity.

When once the nature of the α- and β-particles had been established and the long series of radioactive changes in uranium, thorium, and actinium had been mostly made clear, it appeared that the main contribution of radioactivity to our knowledge was nearing an end. But it is characteristic of this subject that no sooner does it appear to be visibly moribund than it flashes out again into vigorous life, leading to new and unexpected additions to our knowledge. This is well illustrated by the work of the next few years, 1911–13, which saw three new advances of great significance for the future—I refer to the idea

of the nuclear structure of atoms, the conception of the isotopic constitution of the elements, and the proof of an extraordinarily simple relation between the chemical properties of the radio-elements known under the name of the "displacement law."

The discovery of the electron in 1897 and the proof that it was a constituent of all atoms gave a great impetus to the belief that atoms were electrical structures. In 1904 Sir J. J. Thomson had proposed his well-known model atom and devised methods for estimating the number of electrons contained in each atom. On account of its mass and great energy of motion, the α-particle offered great advantages as a projectile to investigate the inner structure of atoms. It was known that it traveled through matter in nearly a straight line and must penetrate freely the structure of the atoms in its path. In addition, the scintillation method provided a delicate means of counting individual α-particles. The proof that the α-particle occasionally suffered a deflection through a large angle as the result of a single collision provided clear evidence that enormous deflecting forces existed within the atom. From these observations, I was led in 1911 to the idea that the atom was a very open electronic structure containing at its center a very minute charged nucleus in which most of the mass of the atom was concentrated. The properties of the atom were defined by an integer representing the number of units of resultant charge carried by the nucleus. The fine experiments of Geiger and Marsden gave convincing evidence of the accuracy of the laws of scattering of α-particles calculated on this hypothesis and also gave us approximate estimates of the nuclear charge of the elements. As you know, this conception that the properties of the atom are defined by an integral number was verified and extended by the splendid experiments of Moseley on the X-ray spectra of the elements. He showed that the properties of an atom depended on its ordinal number, and identified this with the nuclear charge—a result later substantiated by Chadwick by direct determination of the nuclear charge by scattering experiments. Moseley's work was of far-reaching importance, for it fixed once for all the number of the elements between hydrogen and uranium and gave the atomic number and X-ray spectra of the missing elements, several of which have since been discovered.

The next two important discoveries were a direct consequence of a very careful study of the chemical properties of the radio-elements. Several observers had noted that it was impossible, chemically, to separate certain radioactive elements when mixed together; for example, thorium and ionium, radium-D and lead, radium and mesothorium, although these elements showed quite distinctive radioactive properties and were believed to be of different atomic weights. Soddy concluded that these elements of identical chemical properties must occupy

the same place in the periodic table, and gave them the name of "isotopes." This was the first time that proof had been obtained that an element might be complex and consist of atoms differing in mass and structure. The complexity of the radio-elements is now well established. The three well-known radioactive series contain, for example, six isotopes of thorium, three of radium, seven of lead, and seven of polonium, and each of these isotopes shows a different mass and distinctive radioactive behavior.

The next notable advance was the proof that the position of a radio-element in the periodic table had a very simple connection with the type of radiation emitted by the parent product. Soddy had early noted several cases in which the emission of an α-particle, which carries two units of positive charge, gave rise to a product which had the chemical properties of an element two places preceding its parent in the periodic table. We now know that the effect of an emission of a β-particle, which carries only one unit of negative charge, is a corresponding displacement of one group in the opposite direction. The more complete generalization had to await a more definite knowledge of the chemical nature of some of the products, much of which was supplied by the careful work of Fleck. The essential features of this process, known as the displacement law, were put forward about the same time in 1913 by Fajans, by A. S. Russell, and by Soddy, and not only included within their scope nearly all the radioactive bodies in the three main families, but even predicted the properties and positions of elements hitherto unobserved. The proof of this relation indicated that the periodic grouping of the elements was closely connected with the loss or gain of charge of the atom due to the expulsion of an α- or β-particle.

While the displacement law, as put forward, is quite independent of any special theory of the atom, yet we see that it is in complete accord with the nuclear theory if we suppose that the α- and the β-particle are released from the nucleus. The atomic number and atomic weights of uranium and thorium being known, the atomic number and weight of each of the successive elements can be written down from a knowledge of the radiations emitted by each element, illustrating the extraordinary simplicity of the laws which hold for atomic nuclei.

The new conception of the isotopic constitution of the radio elements naturally had a great influence in promoting experiments to decide whether the ordinary inactive elements also were complex. Very largely owing to the pioneer work of Aston, the broad features of the isotopic constitution of the great majority of the elements were soon established, indicating that the varieties of stable atoms were much more numerous than had been supposed.

ARTIFICIAL TRANSMUTATION

We now come to a discovery, the proof of the artificial transmutation of the elements, which has led to a wide extension of the field of radioactivity. A few words should first be said of the theoretical aspects of this problem as they appeared to be in 1918. On the nuclear theory, an atom could only be changed by altering in some way the charge or mass of the nucleus, or both together. It was known that the nucleus was of exceedingly minute dimensions with a radius of the order 10^{-12} cm and must be held together by exceedingly powerful forces in order to prevent its spontaneous disruption. In order to transform an atom, it thus seemed clear that a very concentrated source of energy must be brought to bear on the individual nucleus. Actuated by these ideas, I began experiments in 1917 to test whether the bombardment of light elements by energetic α-particles might lead to the occasional transformation of a nucleus as the consequence of a direct collision between the nuclei concerned. It could be calculated that in such an encounter the α-particle must come very close to the nucleus, even if it did not penetrate its structure. Such a close approach must in any case give rise to enormous forces between the α-particle and the nucleus which might be expected to produce such a distortion of its structure as to result in the disintegration of the nucleus. The scintillation method was employed to detect whether any fast particles appeared under such an intense α-particle bombardment. No effect was noticed for carbon or oxygen, but a number of fast particles were observed in the case of nitrogen, which were identified as swift hydrogen nuclei, now known as protons. It seemed clear that these protons could only arise as the result of the transformation of the nitrogen nucleus. In the light of later results, the essential processes involved in this transformation are now clear. Occasionally an α-particle actually enters the nitrogen nucleus and forms a new atom like fluorine of mass 18 and nuclear charge 9. This new nucleus is unstable and instantly breaks up with explosive violence, hurling out a fast proton and leaving behind a stable nucleus corresponding to a stable isotope of oxygen of mass 17. On an average only one α-particle in 100,000 is effective in producing such a transformation.

With the help of Chadwick, it was soon found that 12 of the light elements could be transformed in a similar way with the emission in each case of protons, but with different speeds and numbers. Time does not allow me to discuss later important developments which have shown that groups of protons of different velocities are ejected from each element and which have proved that resonance levels exist within the struck nucleus favoring the capture of α-particles of definite speed. Further investigation led to a dis-

covery by Chadwick in 1933 of great significance. The element beryllium when bombarded by α-particles does not emit protons but a new type of particle of mass about 1 and zero charge called the neutron. This new particle has remarkable properties, since, owing to its absence of charge, it can pass freely through the structure of atoms. Occasionally, it collides elastically with a nucleus, which is set in swift motion, but sometimes it enters a nucleus and is captured by it. The marked efficiency of the neutron in producing transformations in nitrogen, oxygen, and other light elements was early shown by the experiments of Feather and Harkins, and, as we shall see, has led to very wide developments in the last 2 years. Before, however, discussing these advances, I must refer to another discovery of outstanding importance made by M. and Mme. Curie-Joliot in 1933, in which they showed for the first time that veritable radioactive bodies could be artificially created by the bombardment of certain elements by α-particles. Before this observation, it had been supposed that a stable element or elements were always produced as the result of the atomic explosion. They observed that when boron was bombarded by α-particles, an unstable element was produced which broke up with the emission of fast positive electrons and behaved exactly like a radioactive body of half period 10 minutes. This radioactive body had the chemical properties of nitrogen and the scheme of transformation as given below:

$$^{10}_{5}B + {}^{4}_{2}He \rightarrow {}^{13}_{7}N + \text{neutron}$$
$$\text{and } {}^{13}_{7}N \rightarrow {}^{13}_{6}C + \text{positron}$$
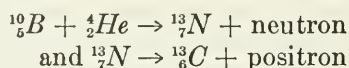
Similarily they found that bombardment of aluminum gave rise to radio-phosphorus of half period 3.2 minutes, which also broke up with the emission of positrons. The formation of radioactive bodies in this way is of great interest, and the appearance of the positron in these transformations is very unexpected.

It was soon shown that artificial radioactive bodies could be produced in various elements not only by bombardment with α-particles but also by protons, neutrons, and deuterons. In particular, Fermi and his collaborators showed that neutrons were exceedingly effective in producing radioactive bodies by bombarding the heavier elements, and more than 50 of these radioactive bodies were soon discovered, each with a characteristic period of decay. In contrast to the radioactive bodies produced by the α-rays in light elements, in the case of the heavier elements, the radioactive body emitted during the transformation not positive but negative electrons. In a number of cases, the chemical properties of the radioactive body have been determined and the scheme of transformation made clear, but obviously time will be required to make sure of the process of transformations in elements which consists of a number of isotopes.

Fermi made another observation of great interest when he found that in the case of some elements, slow neutrons were much more effective in producing transformations than fast ones. Slow neutrons can be readily produced by passing the fast neutrons formed in a transformation through a considerable thickness of hydrogen-containing material, for example, water or paraffin. This aspect of the problem is now under intensive investigation throughout the world, and certain general conclusions have been reached. For fast neutrons, the cross-section of the atom for capture of the neutron varies somewhat from element to element, but is of the order 10^{-24} cm.^{2} For slow neutrons, however, the cross-section for capture for some elements may be from 100 to 10,000 times greater than for fast neutrons. For example, cadmium and boron readily absorb slow neutrons and a still stronger absorption is shown by europium and gadolinium. So marked is the effect of the latter that a layer a small fraction of a millimeter thick is almost a complete absorber for slow neutrons. It is natural to suppose that absorption of the neutrons in an element is a sign of its transformation, even though it may not be easy to obtain proof of the exact nature of the transformation. There is now clear evidence, as shown by Moon and others, that some of the slow neutrons which are effective have thermal velocities. Still more remarkable, absorption in some elements seems to take place over a small range of velocities, a result which may indicate that there are very low energy resonance levels in some nuclei.

The ease with which slow neutrons are able to enter the nucleus of even the heaviest elements has proved of great service. The use of the neutron as a projectile has disclosed the existence of 50 or more ephemeral elements of the radioactive type, representing unstable varieties of isotopes of the elements, and has thus much extended our knowledge of atomic species. Most of these unstable atoms appear to be transformed directly into a stable atom, but in the case of the heavier elements it is quite likely we may be able to produce radioactive atoms which may break up in a succession of stages like the atoms of uranium and thorium. Professor Hahn and Fraulein Meitner, and also M. and Mme. Joliot-Curie conclude that a radioactive element of this type is formed by the action of slow neutrons on thorium, but the evidence is yet not complete. It will be a matter of great interest if we are able to create in this way new radioactive families for study.

My time is too limited to discuss with any detail the large number of new types of transformation which can be brought about by using fast protons and deuterons as projectiles. In some cases, the element formed by the capture of the incident particle breaks up into fragments; in others, a new stable element is formed, and in others a radioactive element. The use of deuterons as projectiles has disclosed

many new and interesting types of transformation, in which either
a proton or a neutron is released. One of the simplest and most strik-
ing of these transformations is produced when deuterium is
bombarded by its own ions. Oliphant and others have shown that
two distinct types of transformation occur:

$$_1^2D + _1^2D \rightarrow _1^1H + _1^3H$$
$$\text{or} \rightarrow _0^1n + _2^3He$$
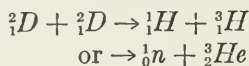
In one case, a fast proton and an isotope of hydrogen of mass 3 ap-
pear; in the other, a fast neutron and an isotope of helium of mass
3. The masses of these hitherto unknown isotopes can be deduced
with confidence from a consideration of the energy changes. Both
of these isotopes are believed to be stable. While ^2H and ^3H and
^3He appear in several other transformations, no certain evidence has
so far been obtained of the isotope of helium ^5He. A stable isotope
of beryllium of mass 8 is also formed in certain transformations as
well as radioactive isotopes. It is worthy of note that apart from
the mass 5, all the masses from 1 to 20 on the atomic scale are repre-
sented either by stable or by radioactive atoms.

CONSERVATION OF ENERGY IN TRANSFORMATIONS

In the transformation of the light elements by bombarding par-
ticles, the energy released per atom is of the same order of magni-
tude as that observed in the radioactive bodies. In a few cases,
particularly when deuterons are employed, the release of energy is
considerably greater, and α-particles are expelled with higher speeds
than from the radio-elements. In some cases too, penetrating γ-rays
are emitted of high quantum energy. For example, the bombardment
of ^7Li by protons gives rise to intense γ-rays of quantum energy as
high as 16 million electron-volts—five times greater than the most
penetrating γ-rays from radioactive bodies.

It is in general believed that the principle of the conservation of
energy holds in these nuclear reactions when account is taken of the
change of mass in the system before and after transformation. The
equivalence of mass and energy seems now well established. A
decrease of mass dm of a system corresponds to an emission of energy
c^2dm, where c is the velocity of light. This law of equivalence is
well illustrated in the transformation of the lithium isotopes by pro-
tons and deuterons shown below:

$$^7Li + ^1H \rightarrow ^4He + ^4He$$
$$^6Li + ^2D \rightarrow ^4He + ^4He$$
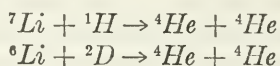
The relative masses of the nuclei involved are known from the ac-
curate measurements of Aston and Bainbridge by the mass-spectro-

graph. The difference between the masses on the left- and the right-hand side of equation (1) is 0.0181 on the atomic scale, corresponding to a change of energy of 17.1 million electron-volts. This is in close accord with the accurate measurements of Oliphant and others of the energy of the expelled α-particles, viz, 17.1 million volts. Similarly, kinetic energies of the α-particles liberated in equation (2) are 22.5 million volts, and this is found to agree well with the change of mass of the system.

As far as our observations have gone, the conservation not only of energy but also of momentum and nuclear charge appears to hold in all nuclear reactions where the energy is liberated in the form of massive particles. In the cases, however, in which either positive or negative electrons are expelled in the transformation, there are certain difficulties in interpretation which have not yet been resolved.

The application of the law of conservation of energy to nuclear changes promises to give us very accurate and reliable data on the relative masses of the atomic nuclei—probably far more precise than we can hope to obtain by the mass-spectrograph, especially in the case of the heavier elements. The transformation data are in some cases inconsistent with the measurements of the masses by Aston and others, and a new scale of masses was recently suggested by Oliphant and Bethe which fit closely with observation. New measurements by Aston and others to fix the masses of the light elements with the greatest possible precision are now in progress, and it seems likely that the new values will be in much closer accord with those deduced from transformation data. It is noteworthy that practically every type of nuclear reaction takes place which is consistent with the laws of conservation, although the probability of the different reactions may vary widely. This is very well illustrated by the great variety of transformations that have been observed in the light elements like lithium, beryllium, or boron when bombarded by different types of particle.

STRUCTURE OF RADIOACTIVE NUCLEI

The discovery of the neutron has much simplified our conception of the structure of nuclei, which are now believed to consist of neutrons and protons with probably helium nuclei as secondary units, composed of a very stable combination of two protons and two neutrons. These particles are contained in a minute nuclear volume with radius of the order 5×10^{-13} cm which is surrounded by a high-potential barrier that prevents the escape of the particles. In the case of a heavy nucleus like that of uranium, where the potential barrier is very high, about 20 million volts, the α-particle has not sufficient energy to escape over the barrier. On wave-mechanical principles,

however, there is a small but finite probability that the α-particle may escape through the barrier, carrying with it the energy which it possesses within the nucleus. Such a view gives a rational explanation of the spontaneous radioactivity shown by uranium and thorium and their products, and also accounts in a general way for the well-known Geiger-Nuttall empirical relation which shows a close connection between the speed of the expelled α-particle from an element and the period of its transformation. In addition, Gamow has shown that on the wave-mechanics a charged particle like a proton has a small probability of entering a nucleus even if its energy is much too small on classical views to approach close to the nucleus. This theory accounts for the observation that comparatively slow particles can cause transformations, and also for the increase of efficiency of transformation with rise of energy of the bombarding particle.

It is difficult to obtain convincing evidence of the relation, if any, between the two units of structure of the atom, the neutron, and the proton. It is difficult to measure the mass of the neutron with accuracy, but the evidence indicates that it is slightly heavier than the mass of the proton. It appears likely that the proton and neutron are closely related and under some conditions are mutually interchangeable within the nucleus.

The expulsion of a negative electron from the nucleus may be connected with the change of a neutron into a proton, while the escape of a positive electron may be connected with the reverse operation. The peculiarities of the emission of electrons, both positive and negative, from radioactive atoms may possibly be traced to this interchange.

Before any detailed theory of nuclear structure can be attempted, it is necessary to find the nature and magnitude of the forces at small distances between the various components of the nuclear structure. Important information on these points ought to be obtained from a close study of the scattering of protons and neutrons in hydrogen. In default of any complete theory, some of the outstanding features of the relation between nuclei—for example, the differences between even- and odd-numbered elements—can be explained in a general way by assuming special types of forces between the elementary particles.

The spontaneous transformation of the radioactive bodies gave us the negative electron and α-particle as constituents of nuclei; the study of artificial transmutation has given us in addition three new particles, the proton, neutron, and positive electron, as well as a host of new radioactive bodies. In addition, as we have seen, we owe our conception of isotopes to the study of the chemistry of radioactive

bodies, and our views of the nuclear structure of all atoms to observations on the scattering of α-particles.

It is clear that the study of radioactivity, both old and new, has been extraordinarily fruitful in extending our knowledge of the nature and varieties of atoms and of the way in which one atom can be changed into another. Although much progress has been made in the last few years, much still remains to be done before we can hope to understand how the atoms have been built up from elementary particles or to grasp the significance of the relative abundance of the varieties of atoms in our earth.

THE CRYOGENIC LABORATORY AT LEIDEN [1]

By Robert Guillien

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[With 5 plates]

INTRODUCTION

In 1882 Kamerlingh Onnes was appointed professor and director
of the physical laboratory of the University of Leiden. Two years
previously Van der Waals had deduced from his equation the law
of corresponding states. Kamerlingh Onnes undertook to verify
this law which he himself had also found from considerations of
similitude. Realizing that for substances liquid at ordinary tem-
peratures there is often decomposition at temperatures below the
critical point, Kamerlingh Onnes preferred to deal with substances
which are gaseous at ordinary temperatures. He proposed to refrig-
erate and liquefy these gases. For measurements on their equations
of state as liquids, it is necessary to produce very low temperatures
and maintain them constant.

Also by a happy intuition, Kamerlingh Onnes conceived that at
low temperatures the properties of bodies should obey more simple
laws and be easier to interpret than the laws of bodies at ordinary
temperatures. He therefore desired not only on the one hand to
study the properties of liquids at low temperatures, but on the other
to obtain low temperatures in order to be able to investigate the
properties of substances in general.

The laboratory had at the start the cycle of methyl chloride, and
then the cycle of liquid ethylene, condensed under pressure after
cooling with methyl chloride. This led to the liquefaction of oxygen
in 1894 by means of preliminary cooling under compression and
refrigeration by liquid ethylene. The liquefaction of hydrogen was
then attempted, but this time by the method of Linde. In 1906 the
first measurements were made in a bath of liquid hydrogen. Going
still further, Kamerlingh Onnes succeeded in 1908 in liquefying

[1] Translated by permission from Revue Générale des Sciences, vol. 47, no. 4, Feb. 29, 1936.

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helium. This enabled him in 1911 to observe temperatures between 2° and 4° K. (absolute). By this time the original program of researches had, of course, been amplified and extended to cover all branches of physics at low temperatures.

After the death of Kamerlingh Onnes, the researches were pursued under the joint direction of Professors Keesom and De Haas. In a general way, although without absolute separation, the investigations carried on under the direction of Professor Keesom concerned thermodynamics, while those directed by Professor De Haas had to do with magnetism and electricity.

PRESENT ORGANIZATION OF THE LABORATORY

The laboratory is devoted to pure research for the study of the properties of substances at low temperatures and of the means of producing low temperatures.

(a) *Production of cold.*—The celebrated cycle by cascade (methyl chloride, ethylene, oxygen, air, hydrogen, helium) is now abandoned. Today the laboratory obtains almost on a commercial scale the production of liquid air and liquid hydrogen. Air is compressed by a machine of 60 horsepower to a pressure of 200 atmospheres. One part is then expanded to 1.2 atmospheres, producing exterior work which is used to compress air, and then finally further expanded to 1 atmosphere. The remaining part is expanded from 200 to 1 atmosphere, liquefying without having produced external work.

In this way the laboratory is able to produce 30 liters of liquid air per hour, or 13,000 liters per year. The liquid air is conserved in Dewar flasks of 5 liters capacity that will keep it about 15 days. In the liquid air laboratory is also an apparatus with which liquid oxygen and liquid nitrogen may be obtained by separating these gases from air under compression and cooling by liquid air.

Liquid hydrogen is obtained by compressing the gas to 180 atmospheres in an 18-kilowatt compressor, then cooling it to the temperature attained by liquid air boiling under reduced pressure, and finally further cooling it after the method of Linde. Production of liquid hydrogen may reach 16 to 18 liters per hour, or 6,000 liters per year. Liquid hydrogen is preserved and transported in special Dewar flasks. Helium is stored in steel cylinders. Compressed to 15 atmospheres, it is then cooled in a coil bathed by liquid hydrogen at −258° C., and finally liquefied by the Linde process. About 3 liters per hour may be produced, and since 1923 a supply of it has been kept up for the cryostats which are used in the various rooms of the laboratory.

(b) *Preparation of apparatus.*—Dewar flasks (cryostats) are necessarily much employed in the researches. Their forms, dimensions, and interior construction vary with different investigations. Most

of these cryostats and other special apparatus are constructed in the laboratory. Kamerlingh Onnes established a school for the instruction of young artisans. They are selected by competition and pass practical examinations from time to time. They receive instruction in general theory, science, design, electrotechnics; and when they leave the laboratory after a 5-year course, are employed in the PTT, the University laboratories, the state industries, etc. The facilities include two glass-blowing rooms, four precision instrument shops, and an optical laboratory. In these work rooms the laboratory employs about 80 young artisans in the construction of cryostats, the liquefaction of gases, and other useful tasks under the direction of 15 foremen. Thanks to these numerous trained and experienced workers, most of the apparatus for the researches is constructed and repaired at the laboratory, with resulting great economy of time. A drafting force installed at the laboratory prepares the working drawings for new apparatus, and the illustrations for publication of the Communications of the laboratory.

(c) *Measurements.*—The investigations nearly always require the determination of at least one temperature. In general, the measurement is made by means of an electrical resistance thermometer, controlled by gas thermometry. To furnish heat during investigations of bodies contained in Dewar flasks for studying their properties, electrical current is supplied to measured resistances. For nearly all researches involving electrical measurements, the cryostats in which are enclosed the substances to be examined, are in connection with an electrical testing room equipped with galvanometers and other apparatus suited to making these measurements in conditions of precision and comfort. When it is necessary to measure simultaneously several electric currents or resistances, the work is nearly always done by several assistants in telephonic communication with the experimenter at the cryostat. Collaboration is also desirable, though in somewhat less degree, when temperature measurements are associated with the pressure of a saturated vapor as observed with the cathetometer. For it is then necessary to hold the temperature constant (or sometimes to cause it to vary in a chosen manner) during the progress of the experiment.

The low temperatures are produced in the 21 experiment rooms by making a reduction of pressure of the appropriate liquefied gas with which the cryostat walls have been filled. Three pumps maintain pressures below 5 millimeters of mercury, available for the whole laboratory.

(d) *Interpretation of observations.*—A special computing room equipped with calculating machines, tables of constants, tables of functions, and other aids is at the disposal of the investigators. It is

there also that discussions of the work in progress take place. There, too, Professor Keesom has given, under the auspices of L'Institut International du Froid, a course in thermodynamics for the research men at the laboratory. They also have access to the library of the laboratory, and also to that of the Bosscha Institute for Theoretical Physics, where they find all the books and periodicals which they are apt to require. This Institute, indeed, is under the direction of Professor Kramers.

(e) *Instruction in physics.*—On the first floor of the laboratory is given instruction in physics for students of the University of Leiden. The courses are given by Professors Keesom, De Haas, Crommelin, and Kramers, and Mrs. De Haas. They prepare for examinations corresponding to a certificate of licentiate.

Large halls, equipped in the most modern fashion, serve for illustrative experiments conducted by assistants. These assistants, 13 in number, may at the same time undertake researches in the laboratory leading to the doctor's degree of the University of Leiden.

INVESTIGATIONS ACCOMPLISHED AT THE LABORATORY

It is not possible to cite here all the researches made at the Cryogenic Laboratory of Leiden, renamed in 1929 the "Kamerlingh Onnes Laboratory." I may only indicate some of the most important of them, or those relating to problems of special interest.

In its early years the laboratory was not devoted solely to low-temperature researches. It was there that in 1896 Professor Zeeman discovered the magneto-optical phenomenon which bears his name. Lorentz, then a professor at the University of Leiden, found the explanation of the phenomenon, and therein lay the possibility of determining the ratio of the electric charge of the electron to its mass.

On July 10, 1908, Kamerlingh Onnes for the first time obtained helium in the liquid state. Helium gas, compressed to 100 atmospheres, then cooled to $-259°$ C. by liquid hydrogen, was cooled by expansion and became liquid. Since then the low-temperature scale has been extended by the use of helium from $4.°2$ to $1.°2$ K. in ordinary practice, and exceptionally to $0.°71$ K. These temperatures are yielded by operations with liquid helium. At $0.°71$ K. helium is still a liquid, and requires to be compressed to 30 atmospheres to solidify. This was accomplished in 1926 for the first time by Professor Keesom.

The properties of helium have been extensively studied at Leiden. Without speaking of the very precise determinations of isotherms used to define temperatures, one may recall many researches relating to helium. One unexpected discovery is that there are two kinds of helium. First Kamerlingh Onnes and Boks discovered that the curve of density and temperature has a point of inflection at

2.°19 K., so that at that temperature the concavity changes sign. Then Professors Keesom and Wolfke found that the variation of the dielectric constant presented the same singularity as that of density. Finally Professor Keesom and Clusius have shown that the specific heat, c, increases in passing from very low temperatures to a maximum value of 3 at 2.°19 K., then decreases rapidly so that the curve, c, T, also shows a cusp. In consideration of the singularity in the form of this curve, the temperature at which the infection occurs has been designated by the Greek letter lambda. Clusius showed later that the special temperature lambda depends on the pressure, and that upon a pressure-temperature diagram the curve T_λ, p_λ) divides in two parts the region of liquid helium.

The designations He_{II} and He_I have been given respectively to the colder and the warmer of the two heliums. Miss Keesom has shown that the specific heat discloses an abrupt discontinuity in an interval of less than 1/1000 degree, and that the coefficients of expansion, of compressibility, and of pressure also exhibit discontinuities. The transposition of He_{II} into He_I is in fact the most studied example of what is termed a transformation of the second order. At the present time an investigation is in progress on the behavior of the heat of fusion in passing from solid helium to the states He_I and He_{II}.

The study of the properties of substances gaseous at ordinary temperatures has profited remarkably by the use of low temperatures. In this way a partial separation of the isotopes 20 and 22 of neon has been made on a nearly industrial scale by a fractional distillation of liquid neon. Such a distillation occupies 4 persons during 4 times 24 hours, and after 14 fractional distillations there results 4 liters of neon of atomic weight 20.091, and 4 liters of neon of atomic weight 21.157. By a similar process it is also possible to create differences of the order of 1.5 percent between the densities of fractions of hydrogen, owing to a partial separation of the heavy component.

The structure of solids is studied at low temperatures by means of X-rays. It has been possible to obtain for such study in monocrystallic state substances which are gaseous at ordinary temperatures, such as ethylene and nitrogen, and this facilitates the interpretation of the results.

In another field, at the behest of Einstein and after him Debije, many measurements have been made of the specific heats in order to check formulation of the quantum theories. These have led to important modifications of these theories. Recently it has been shown that for some metals the free electrons carry an important part of the specific heats at the low temperatures obtainable with helium. This falls in with the theory of Sommerfeld.

The specific heats are also actively studied for metals and alloys in the supraconducting state. With tin, for example, there is found

a discontinuity as the metal passes over into the supraconducting state.

I ought here to recall that it was in the cryogenic laboratory of Leiden that supraconductivity was first discovered in 1911 by Kamerlingh Onnes. He saw that a resistance apparatus of mercury transformed itself practically into a short circuit at a certain temperature. He then observed the same phenomenon for other metals, as lead, tin, and thallium, and found that the resistance could be reestablished by placing the supraconducting metal in a sufficient magnetic field.

Since then many metals and alloys have been examined. At present one studies principally those monocrystals which give the clearest results. It is found that generally the thermal conductivity of a substance reaches a maximum at nearly the same temperature at which supra-electrical conductivity appears.

Until 1934 no other method of lowering the temperature of helium was known except that of boiling its liquid under reduced pressure. In that way the temperature $0.°71$ K. had been reached, and it appeared to be exceedingly difficult to go lower. But then following an idea of Debije, De Haas, Wiersma, and Kramers utilized the phenomena of adiabatic demagnetization. This was also done simultaneously and independently in America by Giauque. The phenomenon appears as follows: A certain quantity of a salt of iron or of a rare earth metal (paramagnetic) is placed in an enclosure refrigerated by liquid helium. On applying a magnetic field the salt becomes magnetic, and thermal energy appears which is dissipated in the liquid helium. If now the salt is thermally insulated from the helium bath, and the magnetic field is turned off, the salt is cooled by becoming demagnetized. For if its temperature were to be preserved constant it would be necessary to supply the energy which was lost in the form of heat during magnetization. The lowering of temperature which thus occurs is of course a function of the nature of the salt and of the magnetic field. It remains therefore to determine the temperature thus attained, for it is impossible to be measured by the pressure of a gas or of the vapor of helium, for these are altogether too small at these excessively low temperatures.

As a measure of temperatures between $1°$ and $4°$ K., the magnetic susceptibility, χ, of the salt is employed. In general, χ follows the law of Curie, $\chi T = C$ for small changes of temperature. Hence one may extrapolate the curve (χ, T) up to $T = 0$, and having measured χ, determine T thereby. More definitely, if the law of Curie is followed, and $\chi_0 T_0$ be the values of χ and T before cutting off the magnetic field, and if χ, T, are the ultimate values, then $T_1 = T_0 \dfrac{\chi_0}{\chi_1}$. In this way with a chrome-potassium alum there has been obtained a

temperature of $0.°0044$ K. This low temperature was obtained in a volume of 60 cubic centimeters. The rate of warming was indeed very slow—only $0.°002$ in 30 minutes.

Heretofore no studies have been made of the properties of bodies at these very low temperatures. Thus far experimentation has succeeded only in controlling definitely the temperatures corresponding to the magnetic susceptibility and in measuring their values with precision. The determination of κ for the salt is made with extreme accuracy.

Being thus highly organized and specialized, the cryogenic laboratory of Leiden has attracted numerous foreign scientists. Mme. Curie proved that the radioactivity of radium is unchanged down to the temperature of liquid hydrogen. Boudin studied the coefficient of expansion of hydrogen. Mathias, in collaboration with Dr. Crommelin, measured the rectilinear diameters for many gases, of which the last explored are carbon monoxide and krypton.

At Leiden, also, Pierre Weiss, in a collaboration with Kamerlingh Onnes, studied magnetization to saturation of ferromagnetic substances, and this led to the discovery of the magneton. Jean Becquerel studied the absorption spectra of the rare earths, their decomposition under a magnetic field, the dissymmetry of intensity of the spectral components, and thereby discovered paramagnetic rotary polarization. He showed that it is possible to observe magnetism (in particular with the rare earth elements) by optical methods much more accurately than the magnetic susceptibility may be determined in the ordinary manner. He also demonstrated the important role played by the internal electric field in crystals at low temperatures. One should mention also the experiments made here by Paul Becquerel upon the effect of very low temperatures upon seeds and bulbs of flowers which afterward were normally developed.

I have attempted to describe the present activities of the cryogenic laboratory of Leiden, whose former successes are but stepping stones to advance in new researches. The reader may obtain a fuller account of its history in the description already given by Mathias. I do not wish to close this article without acknowledging how cordially foreigners, and especially the French, have been received at the Kamerlingh Onnes Laboratory, and not only well-known scientists but also young investigators. The professors guide them and help them to master their difficulties. They work in an atmosphere of good comradeship which makes their researches still more pleasant.

BIBLIOGRAPHY

The works of the Cryogenic Laboratory of Leiden are published in Communications from the Physical Laboratory of the University

of Leiden.   Extensive abstracts are published in Rapports des Congrès Internationaux du Froid.

<div align="center">ADDENDUM BY PROFESSOR KEESOM</div>

Since its establishment the excellence of the installation of the Kamerlingh Onnes Laboratory has attracted many foreign investigators.   Numerous American scientists have even crossed the Atlantic to work there.   The following is a summary of their principal investigations:

A. L. Clark, in collaboration with Kuenen, studied the critical properties of the air.   Gray employed a baroscope serving to determine easily, rapidly, and with great precision the densities of gases and vapors.

G. Breit measured the magnetic susceptibility of chromic chloride and of gadolinium sulphate in an alternating field at the boiling temperature of hydrogen.   He was unable to find any evidence of hysteresis in the magnetization of paramagnetic crystals.   He also measured the dielectric constants of liquid hydrogen and oxygen.

In collaboration with Kamerlingh Onnes, Dana measured the latent heat of vaporization of helium and found a point of inflection at $2.°19$ K., which is the point of transition from He_I to He_{II}.   His measures on the specific heat of liquid helium were unable to yield the point of the cusp because the experimental technique had not then been sufficiently developed.

Donald H. Andrews measured the specific heat of certain organic molecules and of lead.

Very recently Dr. Chester W. Clark has made important measurements on specific heats.   For gadolinium sulphate he extended the measurements and confirmed the anomalous behavior of the specific heat at about $3.°8$ K.   For potassium chloride he found that the values of θ of Delbije (defined by the equation $C_v = 466\left(\dfrac{T}{\theta}\right)^3$, C_v being the specific heat at constant volume) do not tend toward zero, as in the metals (silver, for example) but only diminish.   This proves that the anomalous variation of θ for the metals is caused by a specific heat proper to the free electrons.   For, by subtracting this heat from the heat observed for the metals, the values of θ thus obtained give a curve identical with that of potassium chloride. Dr. Clark has also measured the specific heat of nickel, which is ferromagnetic.   Debije's formula is not followed, and the variations from it do not follow exactly the formula of Sommerfeld for the contribution of the free electrons.   These results have inspired Professor Mott to theoretical considerations of much interest.

PLATE 1

THE KAMERLINGH ONNES LABORATORY.

PLATE 2
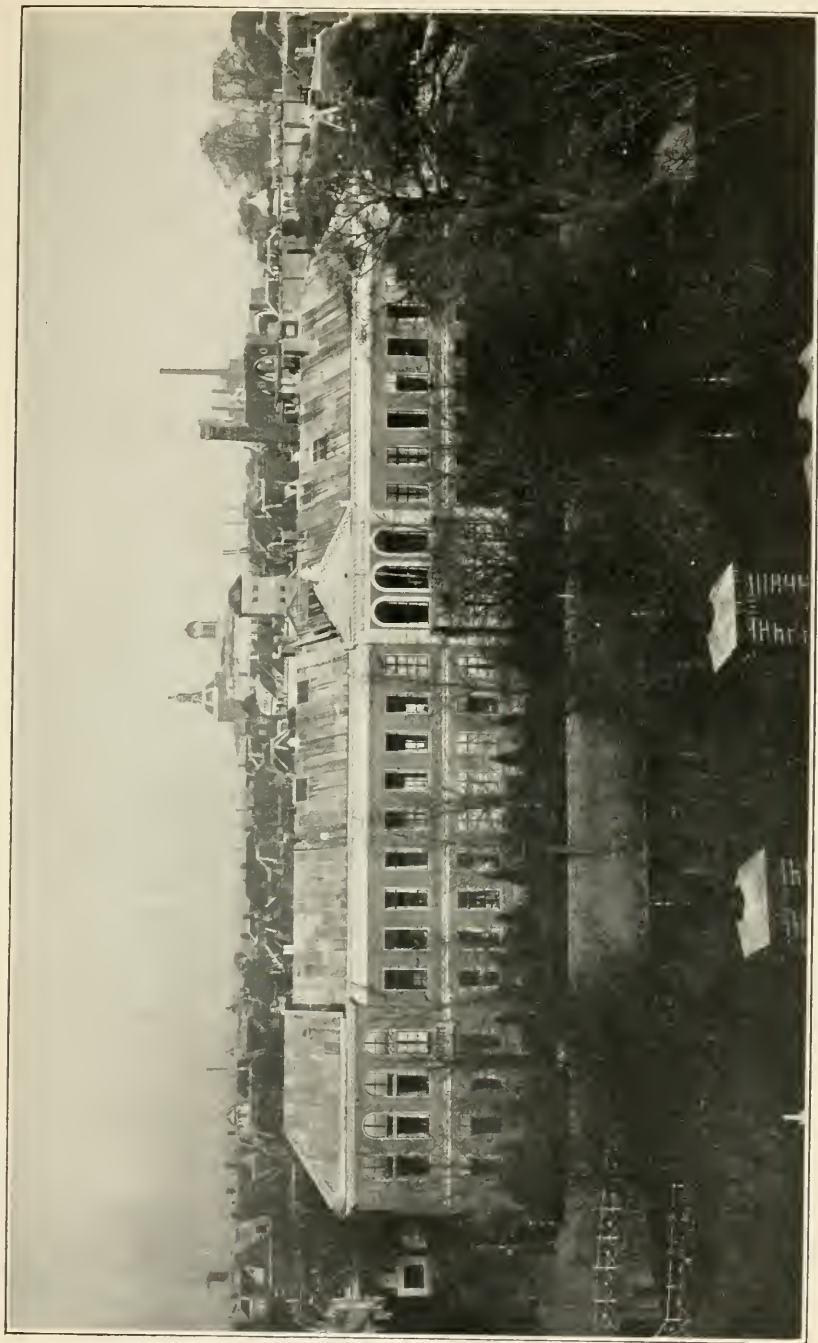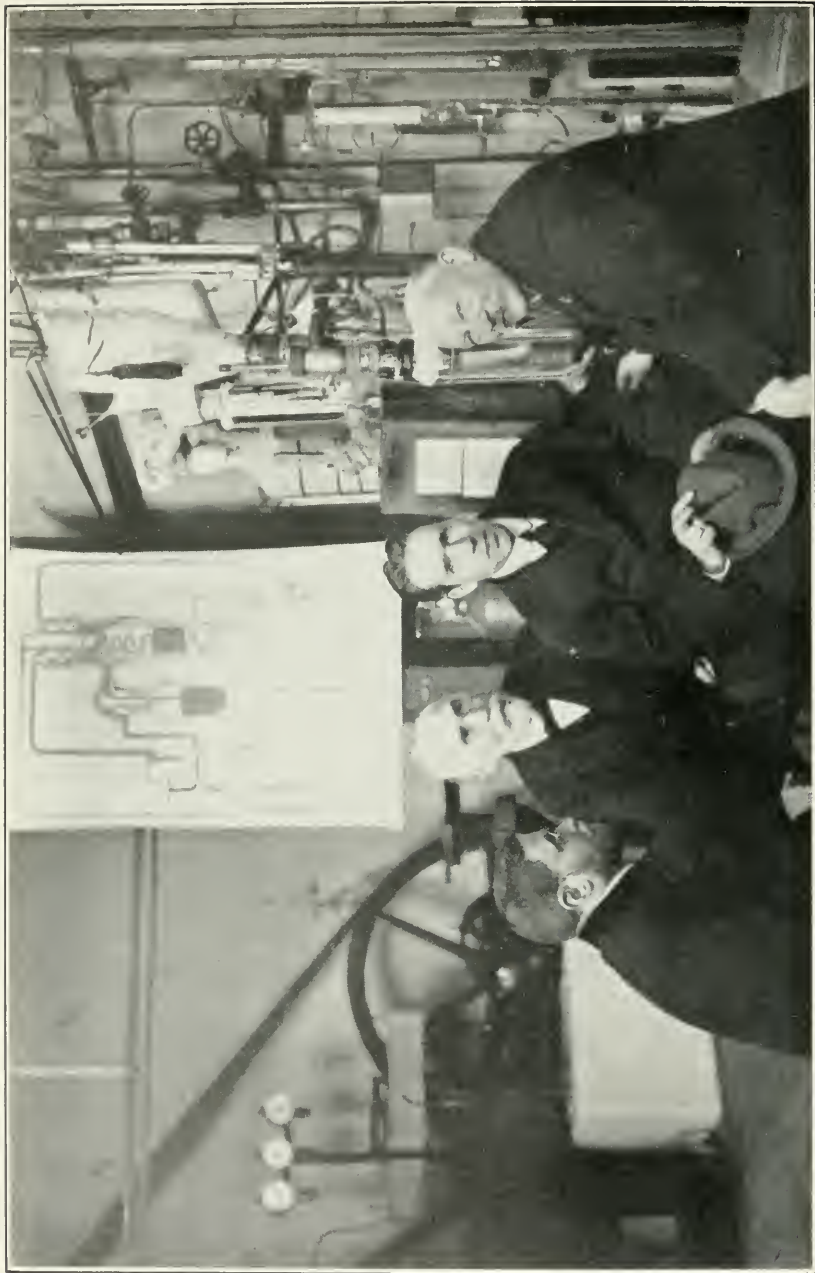
LEFT TO RIGHT: PROFS. P. EHRENFEST, H. A. LORENTZ, N. BOHR, AND KAMERLINGH ONNES.

Photograph taken in 1919. In the background on the left, helium compressor; on the right, helium liquefier, of which a diagram is shown in the center.

PLATE 3
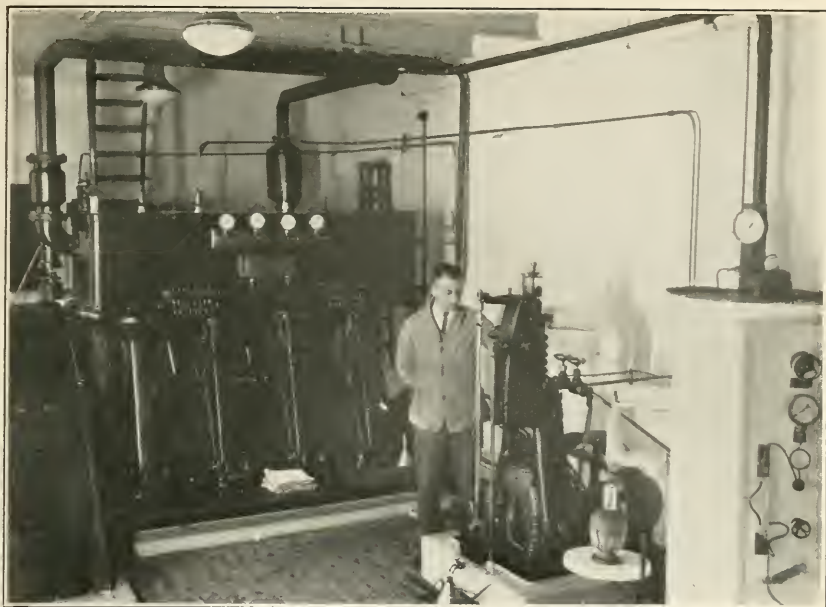
1. ROOM FOR THE PRODUCTION OF LIQUID AIR.

On the left, compressor; on the right, apparatus in which a part of the air is expanded, and liquefier.
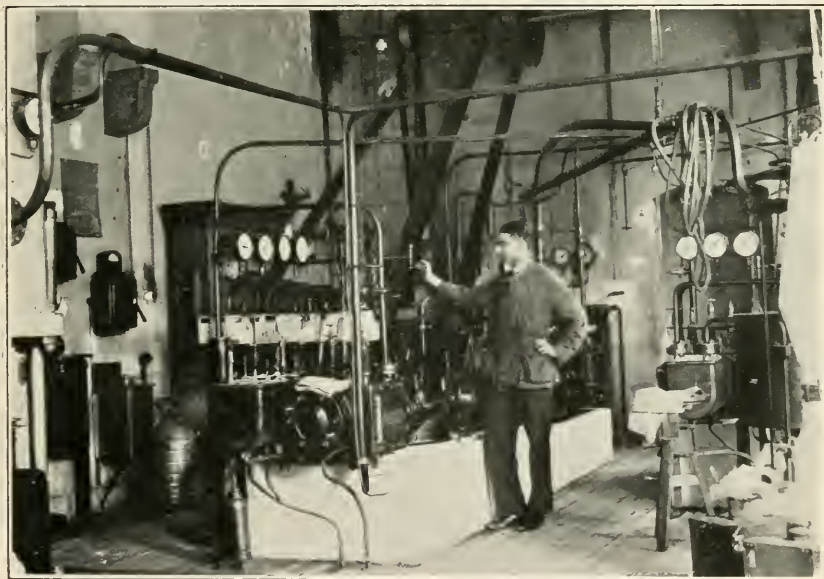
2. ROOM FOR LIQUEFACTION OF HYDROGEN.

On the left and at the center, compressors; on the right, liquefier and receptacles for transporting the liquid hydrogen.

PLATE 4
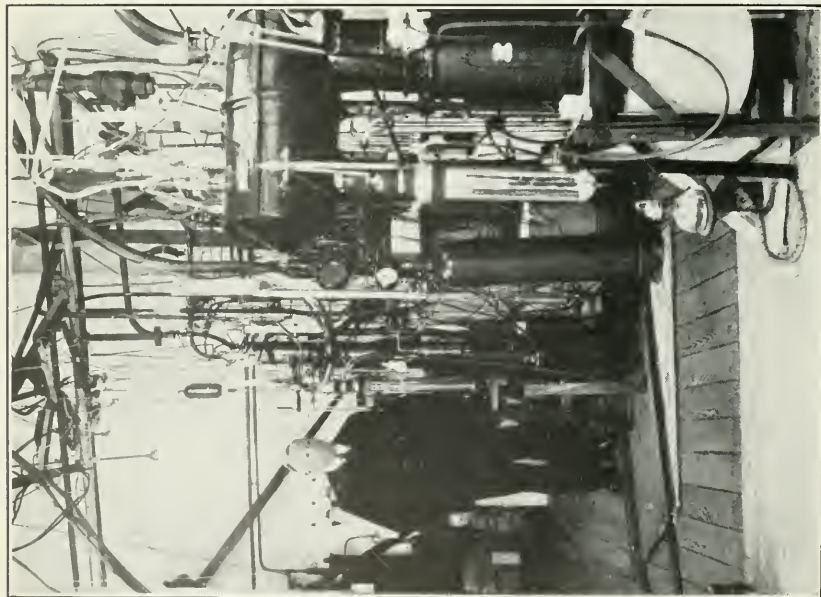
1. PROFESSOR KEESOM BESIDE THE APPARATUS FOR PRODUCING LIQUID HELIUM.
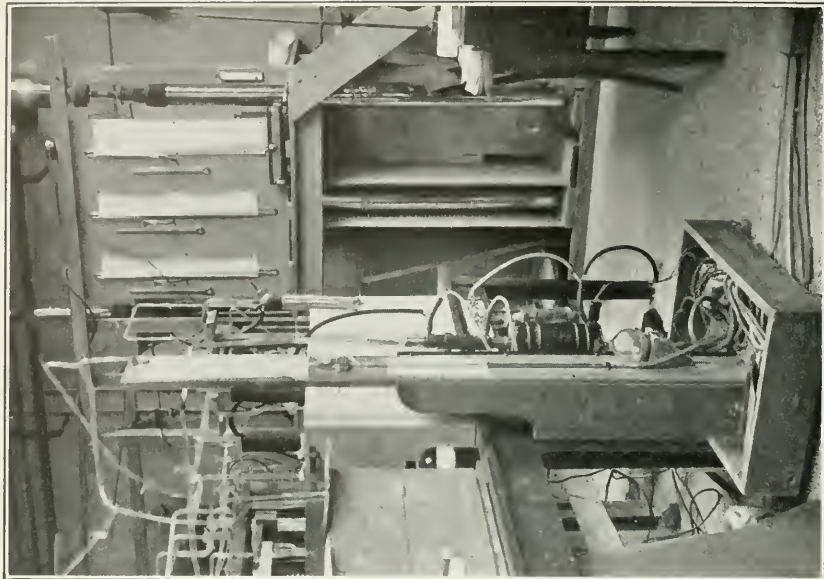
2. ROOM FOR THE SEPARATION OF NEON ISOTOPES.

Copper T 120. On the right, one of the three Dewar flasks, 2 meters high, serving for rectification, and the control manometers. On the left, apparatus for receiving the different fractions of gaseous neon.

1. MM. CROMMELIN AND MATHIAS BY THE APPARATUS WHICH THEY USE TO DETERMINE THE RECTILINEAR DIAMETER OF KRYPTON.

2. M. DE HAAS IN FRONT OF THE ELECTROMAGNET AND THE CRYOSTAT USED FOR ADIABATIC DEMAGNETIZATION.
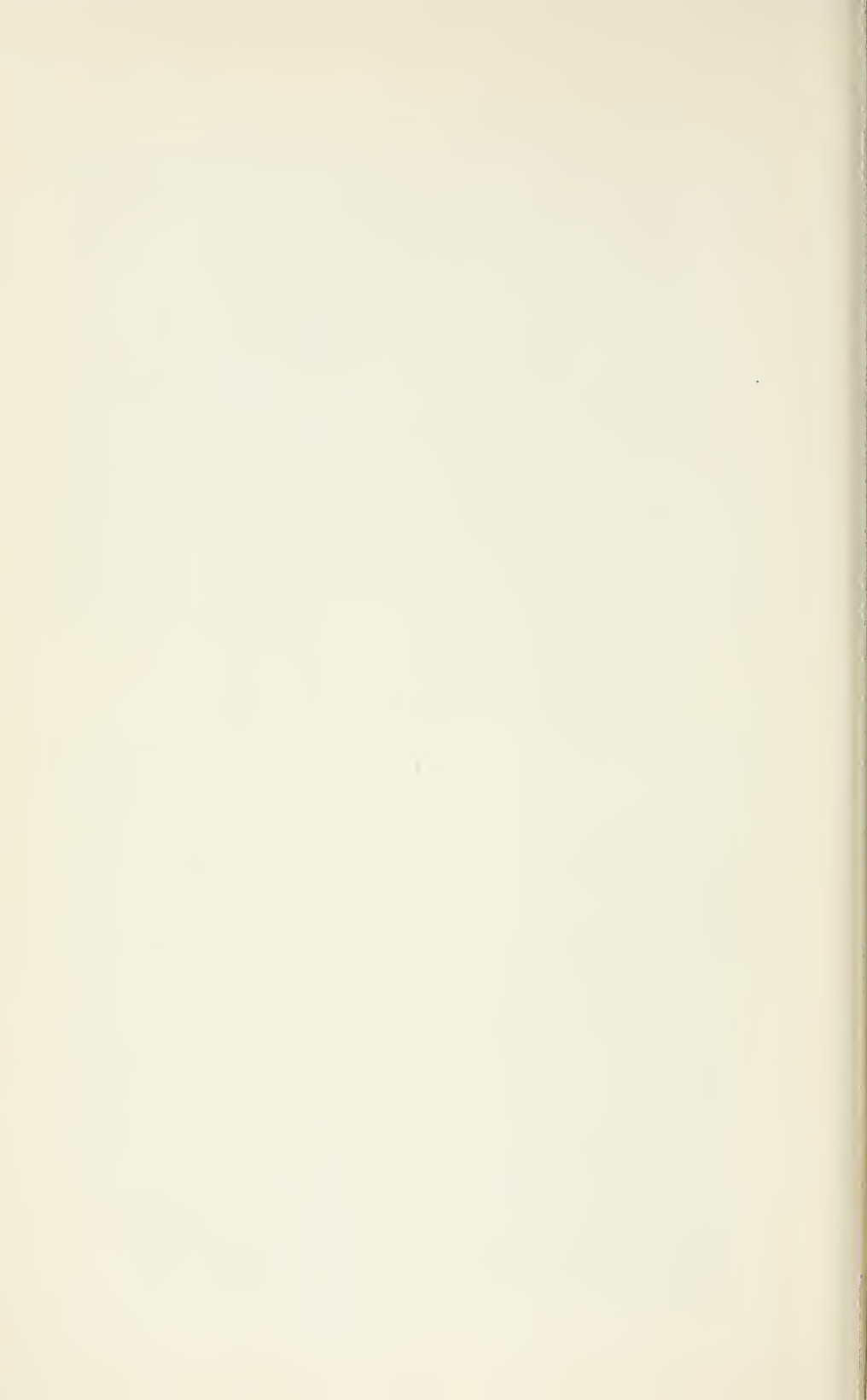
FORM, DRIFT, AND RHYTHM OF THE CONTINENTS [1]

By Prof. W. W. Watts, LL. D., Sc.D., F.R.S.

It is now 67 years since the British Association enjoyed the hospitality of the city of Norwich, a privilege which is being renewed today under the most happy auspices.

At that meeting we find the scientific community was particularly interested in underground temperatures and tidal phenomena, in the application of the spectroscope to celestial objects, and in the discovery of the oldest Cambrian fossils and the earliest fossil mammals then known. Many papers were read on local natural history, including those on Norfolk farming and the drainage of the county and of the Fens.

In his address at the meeting the President, Sir Joseph D. Hooker, made special reference to the work of Charles Darwin: not to the Origin of Species, which had been acrimoniously discussed by the Association on previous occasions, and notably at Oxford in 1860, but to some of the work that followed.

It should be remembered that Hooker was one of the three scientific men, representing botany, zoology, and geology, whom Darwin had selected as judges with whose opinion on the soundness of his theory of the origin of species he would be content. The others were Huxley and Lyell; and of the three Lyell was the hardest to convince, chiefly because the record of life in the past then furnished by the rocks was manifestly so incomplete and unsatisfactory that its evidence was insufficient to warrant a definite verdict.

Lyell had set out to "treat of such features of the economy of existing nature, animate and inanimate, as are illustrative of geology", and to make "an investigation of the permanent effects of causes now in action which may serve as records to after ages of the present condition of the earth and its inhabitants." By laborious study of the work of others, and by his own extensive travel and research, he had been able to enunciate, for the inorganic world, the principle of uniformitarianism, which in its original form we owe to Hutton.

This principle involved that the history revealed by the rocks should be read as the effect of the slow but continuous operation of causes, most of them small, such as could be seen in action in some part or other of the world today. This was set in opposition to the opinion of the older geologists who had postulated a succession of catastrophes which, by flood, fire, and convulsion, had periodically wrecked the world and destroyed its inhabitants; each catastrophe necessitating a new creation to provide the succession of life on the earth as it then was known.

But in the organic world Lyell, like Hutton, had failed to detect any analogous principle, and, as he rejected all the theories of transmutation of species then in vogue, he had to accept their absolute fixity; and to suppose that, as species became extinct one after another, replacement by special creations followed. And yet the reading today of the chapters devoted to this branch in the earlier editions of Lyell's great work produces the haunting feeling that a better explanation had only just eluded him. It was the story revealed in Lyell's work, Darwin tells us, the new conception that the earth had been in existence for vast eons of time, the proof that it had been continuously peopled by animals and plants, and that these had steadfastly advanced and improved throughout that time, which showed him the necessity for an explanation of the progression of life, and gave him the first hints of his theory. When he had enunciated this he was enabled to repay his master with the principle of organic evolution, which brought changes in the animate world into harmony with those of the inanimate.

His Antiquity of Man shows that by 1863 Lyell had become a convert, and he afterwards rewrote much of the second volume of his Principles accepting the new point of view. This change earned from Hooker a testimonial in the 1868 address which, if not unique, must certainly be one of the most magnificent ever awarded to a scientific work:

I know no brighter example of heroism, of its kind, than this, of an author thus abandoning, late in life, a theory which he had regarded as one of the foundation stones of a work that had given him the highest position attainable amongst contemporary scientific writers. Well may he be proud of a superstructure, raised on the foundation of an insecure doctrine, when he finds that he can underpin it and substitute a new foundation: and, after all is finished, survey his edifice, not only more secure, but more harmonious in proportions than before.

Although infinitely richer than when Darwin wrote, the geological record still is, and must from its very nature remain, imperfect. Every major group of animal life but the vertebrates is represented in the Cambrian fauna, and the scant relics that have been recovered

from earlier rocks give very little idea of what had gone before, and no evidence whatever as to the beginnings of life.

But, from Cambrian time onward the chain of life is continuous and unbroken. Type after type has arisen, flourished, and attained dominion. Some of them have met extinction in the heyday of their development; others have slowly dwindled away; others, again, have not finished their downhill journey, or are still advancing to their climax.

Study of the succession of rocks and the organisms contained in them, in every case in which evidence is sufficiently abundant and particularly among the vertebrates and in the later stages of geological history, has now revealed that the great majority of species show close affinities with those which preceded and with those which followed them; that, indeed, they have been derived from their predecessors and gave origin to their successors. We may now fairly claim that paleontology has lifted the theory of evolution of organisms from the limbo of hypothesis into a fact completely demonstrated by the integral chain of life which links the animals and plants of today with the earliest of their forerunners of the most remote past.

Further, the rocks themselves yield proof of the geographical changes undergone by the earth during its physical history; and indicate with perfect clearness that these changes have been so closely attendant on variation in life, and the incoming of new species, that it is impossible to deny a relation of cause and effect.

Indeed, when we realize the delicate adjustment of all life to the four elements of the ancients which environ it, air, water, earth, and fire, to their composition, interrelationships, and circulation, it is perhaps one of the most remarkable facts established by geology that, in spite of the physical changes which we know to have occurred, the chain of life has never snapped in all the hundreds of millions of years through which its history has been traced.

The physical changes with which Lyell and his successors were most closely concerned were, firstly, the formation of stratified rocks on horizontal sea floors, situated in what is now often the interior of continents, far removed from the oceans of the present day, and thus indicating important and repeated changes in the position of land and water; and, secondly, the deformation of these flat deposits till they were rucked and ridged to build the mountain ranges.

Before and since Lyell's time geologists have devoted themselves to working out the exact and detailed succession of these stratified rocks, translating their sequence into history and their characters into terms of geography, the succession of physical conditions prevailing at the time of their formation. Further, although ani-

mals and plants migrate from place to place, the time occupied by the migrations of suitable forms is so negligible when compared with the length of the chapters of geological history that their fossil remains have proved to be the best means for correlating strata over broad stretches of the earth's surface. This correlation has converted the fragments of local history thus revealed into at least the outlines of the geological story of the world.

It was not till 1885, however, that the accumulation of data of this type was sufficient to enable the great geologist, Suess, an Austrian but born in this country, to assemble and correlate them, and to deduce from them further principles which have been the mainstay and inspiration of his successors. We owe to Hertha Sollas and her father the rendering of this great work, The Face of the Earth, into English; and to Emmanuel de Margerie and his colleagues a French translation enriched with a magnificent series of maps and sections such as could only have been brought together by one with the most remarkable bibliographic knowledge; a veritable recension of the original.

The nature and associations and the distribution in time and space of modern changes in the relative levels of land and sea, as detected at sea margins and by altitude survey, and of older changes betrayed by such evidence as submerged forests and raised beaches, had convinced geologists that the unstable element was not the fickle and mobile sea, but the solid if elastic earth crust. They naturally applied the same explanation to those encroachments of the sea in the past which had resulted in the formation of our stratified rocks. But while some investigators were content with one form of movement—that due to lateral pressure—to explain both the formation of mountains and the rise and fall of the land, others called in a different cause for the latter. Without entering into a discussion of causes it may be well for us to distinguish the orogenic or mountain-forming from the epeirogenic or continental movement.

The evidence collected by Suess proved that these last great land and sea changes had occurred simultaneously over whole continents or even wider regions. Such great submergences as those to which the Cambrian rocks, the Oxford clay, and the chalk are due were of this character; while, in between, there came times of broad expansions of continental land and regressions of the sea. These changes were in his view on far too grand a scale to be compared with, or explained by, the trivial upheavals and depressions of land margins of the present day, which he showed could mostly be correlated with volcanoes or earthquakes, or with such incidents as the imposition or relief of ice sheets on an elastic crust in connection with glacial conditions.

It became necessary for him to replace or supplement oscillations of the earth crust by a world-wide periodic ebb and flow of the oceans, to and from the continents; positive movements of transgression carrying the sea and its deposits over the lands, drowning them and their features under tens or hundreds of fathoms of water; and negative movements or regressions when the oceans retreated to the deeps, leaving the continents bare or encrusted with recently formed sediments.

Although the facts cried out for this generalization Suess was at a loss to supply any mechanism competent to produce the wonderful rhythm. The problem was difficult because a liquid must maintain a horizontal, i. e., an equipotential, surface. It was manifestly impossible to withdraw from the earth, and later to replace upon it, the vast quantity of water that would be required; and, though a shifted water level, or even a varied water surface relative to the continents, might be caused by polar ice caps, by redistribution of the continents carrying their local effects on gravitation, by variations in the rate of the earth's rotation, or other far-reaching causes, none of these would supply an explanation that fitted all the facts. Regressions of the sea could be to some extent explained if Suess's main postulate, that the great ocean basins had been slowly sinking throughout geological time, were granted. But this explanation only rendered more impotent the raising of ocean levels by deposits of sediment, and this was almost the only valid cause for transgressions that he had been able to suggest.

Further, it is not possible to ignore the definite relationship that exists between the pulsation of the oceans and the raising of mountains by lateral or tangential stress. Periods of positive movement or advance of the seas were times of comparative tranquillity, when tangential pressure was in abeyance. Periods of negative movement and retreat were invariably marked by the operation of great stresses by which the earth's face was ridged and wrinkled in the throes of mountain birth.

The theory that continuous cooling and shrinkage of the interior of the earth afforded an explanation of mountain ranges and other rugosities on its surface was a legacy from the nebular hypothesis. In spite of the homely simile of a shriveling apple, this explanation has never received a very enthusiastic welcome from geologists, though, in default of other resources, they had to make use of it. As knowledge has grown the difficulties have become insurmountable to them.

First, there is its inadequacy to explain the vast amount of lateral movement required to account for the greater mountain ranges; their rocks, originally spread over a wider area, having been folded

and crushed into a narrower width. The shortening of the earth crust thus effected has been estimated in the case of the Rocky Mountains at 29 miles, of the Himalayas at 62, the Alps at 76, and the Appalachians at the large figure of 200 miles.

Then there is the periodicity of mountain growth. The great epochs of mountain-building, such as the Caledonian, to which the chief Scottish and Welsh mountains are due, the Hercynian, responsible for the Pennine and South Wales, and the Alpine which gave us "the wooded, dim, blue goodness of the Weald", were associated with vast continental development; and each was separated from the next by a period of relative inactivity lasting dozens of millions of years.

Further, there is the fact that the vigor of mountain-building, of volcanoes, and of other manifestations of unrest, has shown no sign of senility or lack of energy. The geologically recent Alpine-Himalayan range is as great, as lofty, and as complicated in structure, as were any of its precursors. The active volcanoes of Kilauea, Krakatao, or St. Pierre, and those recently extinct in Northern Ireland and the Scottish Isles, were as violent and efficient as any of those of the Paleozoic Era. The earth is "a lady of a certain age", but she has contrived to preserve her youth and energy as well as her beauty.

But it was when Lord Kelvin's dictum struck from geology its grandest conception, time, that it became vital to re-examine the position. He had demonstrated that, if the earth had been continuously cooling down at its present rate, its surface must have been too hot for the existence of life upon it a limited number of million years ago. The concept of geological time, indicated by Hutton in his famous saying that in this enquiry "we find no vestige of a beginning—no prospect of an end", had been confirmed by data accumulated through the painstaking researches of a host of competent and devoted observers all over the world. To them, familiar with the tremendous changes, organic and inorganic, that the earth had passed through since Cambrian time, it was wholly impossible to compress the life story of the earth, or the history of life upon it, into a paltry 20 or 30 million years. The slow growth and slow decay of mountain range after mountain range, each built out of, and in some cases upon, the ruins of its predecessor; the chain of slowly evolving organisms, vast in numbers and infinite in variety; told plainly of long eons of time. And the duration of these eons can be dimly realized when it is recalled that, within a small fraction of the latest of them, man, with the most primitive of implements and the most rudimentary culture, has succeeded in penetrating to the uttermost corners of the world, and developed his innumerable languages and civilizations.

Huxley, as our representative, took up the challenge in his address to the Geological Society in 1869, and asked the pertinent question "but is the earth nothing but a cooling mass 'like a hot water jar such as is used in carriages' or 'a globe of sandstone'?" And he was able to point out at least some agencies which might regenerate the earth's heat or delay its loss.

So it is only fitting that the great physicist, who imposed a narrow limit to geological time, should have prepared the way for those who have proved that the earth possesses in its radioactive substances a "hidden reserve" capable of supplying a continuous recrudescence of the energy wasted by radiation, thus lengthening out the time required to complete its total loss. These later physicists have given us time without stint; and, though this time is the merest fraction of that envisaged by cosmogonists and astronomers, we are now so much richer than our original estimates that we are embarrassed by the wealth poured into our hands. So far from the last century's urge to 'hurry up our phenomena", we are almost at a loss for phenomena enough to fill up the time.

The farsighted genius of Lord Rutherford and Lord Rayleigh first saw the bearing of the rate of disintegration of radioactive substances in the minerals of rocks on the age of the parts of the earth crust built of them. The extension and supplementing of this work by Joly, Holmes, and others, has now enabled us to look to the disintegration of uranium, thorium, and potassium, as the most promising of many methods that have been used in the endeavor to ascertain the age of those parts of the earth crust that are accessible to observation. These methods also promise a means of dating the geological succession of eras and periods in terms of millions if not hundreds of thousands of years.

The decline and early death to which Lord Kelvin's dictum had condemned the earth, according so little with the vigor displayed in its geological story, is now transformed into a history of prolonged though not perennial youth. It was for Joly, of whose work the extent, variety, and fruitfulness are hardly yet fully appreciated, to take the next step and see in the release of radioactive energy a mechanism which could drive the pulse that geologists had so long felt, and that Suess had so brilliantly diagnosed. As Darwin found the missing word for Lyell, so Joly in his theory of thermal cycles has indicated the direction of search for a mechanism to actuate the rhythm of Suess.

In Joly's conception the running down of the earth's energy, though a continuous process, was, through the intervention of radioactivity, converted into a series of cycles, during each of which relative movements of sea and land must occur; downward movements of the continents, associated with positive encroachments of the sea;

upward movements, with retreat of the sea, the formation of wide land masses, and the ridging of strata to form mountain ranges. Thus he forged a link that could unite the continental or epeirogenic movement with orogenic or mountain movement.

The visible parts of mountains and continents, as well as their lower and hidden portions, or "roots", are made of comparatively light rocks. In order to stand up as they do their roots must be embedded in denser matter, in which they "float" like icebergs in water. A far larger mass must exist below than is visible above, and the bigger the upstanding part the bigger the submerged root. Over the larger area of the ocean floor, on the other hand, the thickness of material of low density must be very slight, and the denser layer must come close to the surface.

The study of earthquakes, to which the seismology committee of the British Association has made outstanding contributions, has yielded from the times taken in transmission of vibrations through the earth, the best information as to the nature and state of the interior. It has proved that the dense layer is solid at the present time. It is probably no coincidence that the earth is also but just recovering from what is possibly the greatest period of mountain building, if not the greatest negative movement of ocean retreat, that it has ever experienced.

But solidity cannot be the permanent condition of the substratum. Heat is generated in it by its own radioactivity, but according to the terms of the hypothesis, cannot escape in consequence of the higher temperature generated in the continental rocks which cover it. It is therefore retained in the substratum and stored as latent heat of liquefaction, so that within a period which has been calculated approximately in millions of years, complete melting of the subcrust must ensue.

The resulting expansion of the liquefied stratum will have at least two effects of great importance to us. In the first place the unexpanded superficial layers will be too small to fit the swelling interior. They will, therefore, suffer tension, greater on the ocean floor than on land, and cracking and rifting will occur, with intrusion and extrusion of molten rock. In the second place the continental masses, now truly floating in a substratum which has become fluid and less dense than before, will sink deeper into it, suffering displacement along the rift cracks or other planes of dislocation. As a result the ocean waters, unchanged in volume, must encroach on the edges of the continents, and spread farther and farther over their surfaces.

Thus we have the mechanism which Suess vainly sought, causing positive movements of the oceans, their waters spreading over wide stretches of what was formerly continental land, and laying down

as sediment upon it the marine stratified rocks which are our chief witness of the rhythmic advances of the sea.

This condition, however, cannot be permanent, for by convection of the fluid basic substratum, supplemented by the influence of tides within it, and the slow westward tidal drag of the continental masses toward and over what had been ocean floor, there will now be dissipation of its heat, mainly into the ocean waters, at a rate much faster than it has been or could be accumulated. Resolidification ensues, and again there are two main consequences. First, the stratum embedding their roots having now become more dense, the continental masses rise, and as they do so the ocean waters retreat from their margins and epicontinental seas, leaving bare as new land, made of the recently deposited sediments, the areas previously drowned. Secondly, the expanded crust, left insufficiently supported by the withdrawal of shrunken substratum, will suffer from severe tangential stress, and, on yielding, will wrinkle like the skin of a withering apple. The wrinkles will be mountain ranges, formed along lines of weakness such as those at continental margins; and they will be piled up and elevated to suffer from the intense erosion due to water action upon their exposed and upraised rocks.

In this, again, we have a mechanism which supplies what was needed by Suess, and one, moreover, which secures the required relationship between continental and mountain movement, between the broader extensions of continental land and the growth of mountains with their volcanoes and earthquakes and the other concomitants of lateral thrust.

Thus a thermal cycle may run its full course from the solid substratum, through a period of liquefaction accompanied by crustal tension, back to solidification and an era of lateral stress; and the stage is set for a new cycle.

Prof. Arthur Holmes, in checking Joly's calculations, has concluded that the length of the cycles in a basic rock substratum should occupy from 25 to 40 million years, a period much too short to fit the major periods of mountain movement, as determined by him from the radioactivity of minerals contained in the rocks. On this evidence the Alpine movement should date back from 20 to 60 millions of years ago, the Hercynian 200 to 250 millions, and the Caledonian from 350 to 375 million years.

In a preliminary attempt to modify Joly's hypothesis Holmes postulated the occurrence of similar, but longer cycles (magmatic cycles) in a denser, ultrabasic layer underlying the basic one, the rhythm of which would be nearer to 150 million years. The shorter cycles due to the basic layer are held in part responsible for periods of minor disturbance, and also to account for the individual varia-

tions in effect, duration, and intensity of the larger ones. Each of the later movements has also evidently been limited and conditioned by the results of foregoing ones, and especially by areas of fracture and weakness on the one hand, and by large stable masses composed of rocks intensely consolidated, or already closely packed, on the other.

More recently Holmes has developed the possibility that the loss of heat is mainly due to convection in the liquid substrata, and that convection is the leading cause of the drifting and other movements of the crust, and the disturbances that have occurred in it. He says:

Although the hypothesis involving subcrustal convection currents cannot be regarded as established, it is encouraging to find that it is consistent with a wide range of geological and geophysical data. Moreover, it is by no means independent of the best features of the other hypotheses. It requires the local operation of thermal cycles within the crust, and it necessarily involves contraction in regions where crustal cooling takes place. It is sufficiently complex to match the astonishing complexities of geological history, and sufficiently startling to stimulate research in many directions.

The phenomena are difficult to disentangle as the number of operating causes has been so great and many of them are not fully understood. But, underlying them all there is unquestionably the pulse within pulse which Suess saw and of which Joly pointed the way to explanation.

The view at which we have arrived is neither strictly uniformitarian nor strictly catastrophic, but takes the best from each hypothesis. As Lyell showed, most of the phenomena of geology can be matched somewhere and sometime on the earth of today; but it would appear that they have varied in place, intensity, phase, and time. And, as Lyell was driven to accept evolution to explain the history of life on the earth, so must we employ the same word to express the life processes of the earth itself, as was suggested by Huxley in 1869 and strongly advocated by Sollas in 1883.

The contrast in outline and structure between the Atlantic and Pacific Oceans had long been noted when Suess formulated and used the differences as the basis of his classification.

The Pacific is bounded everywhere by steep slopes, rising abruptly from profound ocean depths to lofty lands crowned with mountain ranges, parallel to its shores and surrounding its whole area. On the American side the Coast Range is continued by the Andes. On the Asiatic side chains of mountainous peninsulas and islands, separated from the continent by shallow inland seas, extend in festoons from Kamchatka and Japan to the East Indies, eastern Australia, and New Zealand. This mountain ring, as Charles Lapworth said, "is ablaze with volcanoes and creeping with earthquakes", testifying that it has been recently formed and is still unfinished.

The Atlantic Ocean, on the other hand, is not bordered with continuous ranges, but breaks across them all: the Scottish and Welsh

ranges, the Armorican range, the continuation of the Pyrenees and Atlas; and, on the American side, the uplands of Labrador, Newfoundland, and the eastern States, and the hill ranges of Guiana and Brazil. The Atlantic is in disconformity with the grain of the land, while the Pacific conforms with it. The Pacific has the rock-folds of its ranges breaking like ocean waves toward it as though the land were being driven by pressure to advance upon it, while the Atlantic recalls the effects of fracture under tension.

The middle and southern edges of the Atlantic, however, agree to some extent with the Pacific type. The Caribbean Sea, with the Antilles and the rest of its border girdle, recalls the similar structure of the Mediterranean, as it stretches eastward, with breaks, to the East Indian Archipelago; while the Andes are continued to Antarctica in a sweeping curve of islands. The rest of the Indian Ocean is of Atlantic type, as seen in the shores of eastern Africa and western Australia.

Another feature of the Atlantic is the parallelism of much of its eastern and western coasts, the meaning of which has often attracted the speculations of geologists and geographers. With a little stretch of the imagination, and some ingenuity and elasticity of adjustment, plans or maps of the opposite sides may be fitted fairly closely, particularly if we plot and assemble the real edges of the continents, the steep slopes which divide the "shelves" on which they stand from the ocean depths. This has suggested the possibility that the two sides may once have been united, and have since broken and drifted apart till they are now separated by the ocean.

This view, outlined by others, has been emphasized by Wegener and dealt with by him in full detail in his work on The Origin of Continents and Oceans, and it now plays a leading part in what is known as the Wegener theory of continental drift. The hypothesis is supported by the close resemblances in the rocks and fossils of many ages in western Europe and Britain to those of eastern North America; by community of the structures by which these rocks are affected; and by the strong likeness exhibited by the living animals and plants on the two sides, so that they can only be referred to a single biological and distributional unit, the Palearctic region.

The hypothesis, however, did not stop at this; and in the South Atlantic and certain other areas Wegener and his followers have also given good reasons for believing that continental masses, once continuous, have drifted apart.

Broad areas in southern Africa are built of rocks known as the Karroo formation, of which the lower part, of late Carboniferous age, is characterized especially by species of the strange fernlike fossil

plants Glossopteris and Gangamopteris. Associated with them are peculiar groups of fossil shells and fossil amphibia and reptiles. Similar rocks, with similar associations and contents, in Peninsular India have been named the Gondwana formation. Comparable formations also occupy large regions in Australia, Tasmania, and New Zealand, in Madagascar, in the Falkland Islands and Brazil, and in Antarctica.

The correspondence between these areas is so close that Suess supposed they must at that date have been connected together by lands, now sunk beneath the sea, and he named the continent thus formed Gondwanaland after the Indian occurrences. The break-up of this land can be followed from a study of the rocks, and it was a slow process, its steps occupying much of Mesozoic time. Dr. A. L. du Toit's comparison of South African rocks with those of Brazil and elsewhere in South America favors even a closer union than this between the units now scattered.

One of the most remarkable features shown by these rocks in all the areas mentioned, but to varying extents, is the presence of conglomerates made of far-traveled boulders, scratched like those borne by the modern ice sheets of Greenland and the Antarctic, associated with other deposits of a glacial nature, and often resting upon typical glaciated surfaces. There is no possible escape from the conclusion that these areas, now situated in or near the Tropics, suffered an intense glaciation. This was not a case of mere alpine glaciers, for the land was of low relief and not far removed from sea level, but of extensive ice sheets on a far larger scale than the glaciation of the northern parts of the new and old worlds in the Pleistocene ice age. I have never seen any geological evidence more impressive or convincing than that displayed at Nooitgedacht, near Kimberley; while the illustrations and other evidence published by David and Howchin from Australia are equally striking.

Du Toit's work on these glacial deposits brings out two remarkable facts; first, that the movement of the ice was southerly, poleward and away from the Equator, the opposite to what would be expected, and to the direction of the Pleistocene ice movement; secondly, that the ice in Natal invaded the land from what is now sea to the northeast.

When it is realized that at this period there is no evidence of glacial action in northern Europe or America, but a climate in which grew the vegetation that formed the coal seams of our Coal Measures, it is clear that we are not dealing with any general refrigeration of the globe, even if that would produce such widespread glaciation; we are face to face with a special glaciation of Gondwanaland.

On both sides of the Atlantic these glacial episodes in Carboniferous times were followed by dry and desert climates in Triassic time, and these by violent volcanic outbursts. Nor are the rocks alike only in mode of formation, the structures by which they are traversed correspond; while even in details there is remarkable agreement, as in the peculiar manganese deposits, and the occurrence of diamonds in "pipes" of igneous rock, both east and west of the ocean.

Rather than face the difficulties presented by the subsidence of lands connecting the severed portions of Gondwanaland, as pictured by Suess, Wegener has preferred, and in this he is supported by De Toit and many other geologists, to bring into contact these severed parts, which could be fitted together as nearly as might be expected, considering the dates of severance. Du Toit's map of the period places South America to the west and south of South Africa, Madagascar and India to the east, Antarctica to the south, and Australia farther to the southeast. Such a grouping would form a continent much less wide in extent than that envisaged by Suess, and would offer some explanation of the more remarkable features of the glaciation in the several areas, as well as the problems of the rocks, fossils, and structures involved.

In its application to the geology of Gondwanaland the modified hypothesis of Wegener cuts a Gordian knot; but it still leaves a great climatal difficulty, unless we take his further step and conceive that at this date the terrestrial south pole was situated within Gondwanaland. No shift in the axis on which the earth rotates would, of course, be possible, nor is it postulated; only a drifting at that date of continental land across the pole.

If a hypothesis of drift be admitted for Gondwanaland, it would be illogical to deny its application to other regions, including the North Atlantic. I have already mentioned some facts in its favor. Others are the resemblances of all sedimentary rocks on the two sides from the Cambrian to the Ordovician, and from the Devonian to the Trias; the links between the structures of the land, as, for instance, between Ireland and Newfoundland; and the instance given by Professor Bailey in his address to Section C in 1928. As Bailey then pointed out, the great Caledonian range which crosses Scotland, northern England, and Wales from northeast to southwest on its course from Scandinavia is affected and displaced by the east to west Armorican (Hercynian) chain extending across from Brittany to South Wales. "The crossing of the chains, begun in the British Isles, is completed in New England"; and from here the Armorican structure continues its westerly course. This is where it should cross if the continent of North America were brought back

across the Atlantic and placed in the position which, according to Wegener, it would fit into in the European coast! Can the Pilgrim Fathers have ever dreamed of such a link between the Old England and the New?

The hypothesis of continental drift gave rich promise of solving so many difficult problems that it was hailed by many classes of investigators almost as a panacea. Geographers have seen in it an explanation of the forms of continents and the position of peninsulas, islands, and mountains; meteorologists have found it the solution of some of the problems of past climates and their anomalies of distribution over the world; biologists hope to get help with the intense complexities in the distribution of forms of life and many strange facts in migration, and paleontologists with similar difficulties among the ancient faunas and floras as revealed by their fossil remains; geodesists have welcomed escape from the rising and sinking of the crust, so difficult to reconcile with the demands of isostatic equilibrium; and it has been already stated that drift forms a vital factor in Joly's thermal cycles.

But there has been no lack of criticism in all these directions. It has been assailed on the one hand for the detail attempted in its geographical restorations, and on the other hand for its vagueness. Professor Schuchert quotes Termier as saying that it is "a beautiful dream, the dream of a great poet. One tries to embrace it, and finds that he has in his arms but a little vapor or smoke; it is at the same time alluring and intangible." It has been objected that "no plausible explanation of the mechanics involved has been offered"; that the continental connections postulated present by no means so close a match, when fitted together, as has been claimed, in the structure or the nature of either igneous or sedimentary rocks; that there is good evidence of extensive vertical movements in recent earthquakes, in the accumulation of tremendous thicknesses of sediment indicative of shallow water from base to summit, and in the growth of coral reefs; that Central America and the Mediterranean are a difficult obstacle; and that the known distribution of the Karroo fossil reptiles is not by any means what the hypothesis demands.

If the idea of drift be accepted it cannot be regarded as a royal road out of all our difficulties, nor can it be the only form of earth movement to be reckoned with. The late J. W. Gregory, whose life was sacrificed to geological discovery, has studied exhaustively the geological history of the Atlantic and Pacific Oceans, both as revealed by the sedimentary rocks and fossils on their borders, and by the distribution of life today. He finds that, according to our present knowledge, in the two oceans, facilities for migration have fluctuated from time to time, periods of great community of

organisms alternating with periods of diversity. Again, at some times connection seems to have been established north of the Equator, at others to the south; and we cannot ignore the possibility of migration across polar lands or seas when terrestrial climates have differed from the present. The facts of life distribution are far too complex to be explained by any single period of connection followed by a definite breaking apart, even if that took place by stages. Mrs. Reid, too, has pointed out that resemblances between the Tertiary floras of America and Europe actually increased at the time when the Atlantic should have been widening. Unless continental drift has been a more complicated process than anyone has yet conceived, it seems impossible to escape from some form of the "land bridges" of the older naturalists:

> Air-roads over islands lost—
> Ages since 'neath Ocean lost—

We have no right to expect greater simplicity in the life of a planet than in that of an organism.

As the question of drift must in the last appeal be one of fact, it is not unnaturally expected that the real answer will come from measurements of longitude and latitude with greater exactness and over periods longer than has yet been possible. None of the measurements hitherto made has indicated variations greater than the limits of errors of observation. Two things, however, may militate against a definite answer from this source. Many parts of the crust, such as the shieldlike masses of Archean rock, may have completed their movement, or be now moving so slowly that the movement could not be measured. Careful selection of locality is essential, and at present we have little guidance. Also, as the displacement of crust must be dependent on the condition of its substratum, it will be a periodic phenomenon and the rate of movement may vary much in time. According to the theory of thermal cycles the subcrust is at present solid and may not permit of drift. Drift, according to Joly and Holmes, is a cyclical phenomenon; if present-day observations were to give a negative result they would not necessarily disprove it.

The occurrence of recumbent rock folds and nearly horizontal slides or "nappes" in mountain regions gives positive proof that parts of the upper earth crust have moved over the lower. In the Northwest Highlands of Scotland a sliding of at least 10 miles was proved by Peach and Horne, and in Scandinavia it amounts to 60 miles. For mountain packing as a whole the figures already given are far larger, while in Asia Argand has stated that packing of over 2,000 miles has occurred. Thus, when all is said and done, movements on a colossal scale are established facts, and the question of the future is how far we shall accept the scheme of drift due to

Wegener, or one or other of the modifications of it. It is for us to watch and test all the data under our own observation, feeling sure that we shall have to adapt to our own case Galileo's words "e pur si muove."

Ever since it was realized that the inclination and folding of rocks must be attributed to lateral or tangential stress and not solely to uplift, shrinkage of the interior of the earth from its crust has been accepted as the prime mover, and whichever of the current theories we adopt we cannot deny the efficacy of so powerful a cause.

The general course of events in the formation of a mountain range is fairly well known: the slow sinking of a downfold in the crust during long ages; the filling of this with sediment pari passu with the sinking and associated softening of the subcrust due to accumulated heat; the oncoming of lateral pressure causing wavelike folds in the sediments and the base on which they rest; the crushing of folds together till, like water waves, they bend over and break by overdriving from above or, it may be, underdriving from below; fracture of the compressed folds and the traveling forward for great distances of slivers or "nappes" of rock, generally of small relative thickness but of great length and breadth, and sliding upon floors of crushed rock; the outpouring and intrusion of igneous rocks, lubricating contacts and complicating the loading of the sediments; metamorphism of many of the rocks by crystallization at elevated temperatures and under stress, with the development of a new and elaborate system of planes of reorientation and movement; and elevation of the whole, either independently or by thickening with compression and piling up to bring about a fresh equilibrium.

Such a course of events would be brought about by lateral pressure developed during the consolidation phase of each of the thermal or magmatic cycles. At each period of their building, mountains have arisen along lines of weakness in the crust, especially coast lines and the steep slopes marking the limits between continents and ocean basins. This is consistent with Joly's theory that the thrust of ocean beds against land margins is the cause.

But the advocates of continental drift point to the siting of ranges across the paths along which the drifting movement is supposed to have occurred, and they consider that the moving masses are responsible; and indeed that the ridging and packing of the crust has in the end checked and stopped the movement. They note that the great western ranges of America occur in the path of any western drift of that continent, the Himalayas in the course of the postulated movement of India, the East Indies in front of Australia; and that the Alpine ranges of Europe may be linked with the crushing of Africa toward the north.

The "nappes" of rock, cut off from their origin and sliding for dozens of miles, are a constant source of wonder to all who have considered the mechanics of mountain formation. They are so thin as compared with their great length and breadth, that it seems impossible to imagine them moved by any force other than one which would make itself felt throughout their every particle. Such a force is gravitation, and it is of interest that some Alpine geologists and Dr. Harold Jeffreys have used it in explanation of them. Professor Daly has also adopted gravitation on an even greater scale in his theory of continental sliding; and one cannot fail to notice the increasing use of the term "crust-creep" by those working on earth movement.

Is there no other force comparable in its method of action to gravitation but capable of producing movement of the earth crust in a direction other than downhill? Is it not possible, for instance, that the tidal influence of the moon and sun, which is producing so much distortion of the solid earth that the ocean tides are less than they would be otherwise, and, dragging always in one direction is slowing down the earth's rotation, may exert permanent distorting influence on the solid earth itself? May it not be that such a stress, if not sufficiently powerful to produce the greater displacements of continental drift and mountain building, may yet take advantage of structures of weakness produced by other causes, and itself contribute to the formation of nappes and to other movements of a nature at present unexplained?

Our knowledge of geology has been gained by the survey of the rocks, the study of their structures, and the delineation of both upon maps and sections. This work is being accomplished by geologists all over the world, and this country and its dependencies have contributed their full share. It is therefore opportune to note that there has just been celebrated the centenary of the Geological Survey of Britain and, with it, the opening of the new Geological Museum at South Kensington.

A century ago H. T. de la Beche, one of the devoted band of pioneer workers then studying the geology of the country, offered to "affix geological colours to the new maps of Devon and Cornwall" then in course of issue by the Ordnance Survey. His offer was accepted, and, at his own expense and on his own feet, he carried out a geological survey of some 4,000 square miles. In 1835 he was appointed to continue this task, with a small salary and a few assistants. Thus was started the first official geological survey, an example widely followed by other nations and dominions. De la Beche's conception included also a museum of economic and practical geology, a library, a record of mines, for which he secured support from a strong com-

mittee of the British Association in 1838, and a school of mines for the scientific and technical education of those to be employed in the survey or exploitation of mineral resources. In these objects, and especially the last, he was warmly supported by the Prince Consort. He lived to see his visions all come true, as he collected round himself that wonderful band of surveyors, investigators, writers, and teachers, which included such men as Playfair, Logan, Ramsay, Aveline, Jukes, Forbes, Percy, Hooker, and Huxley.

Some of the schemes he planned have budded off and grown into large and important entities, rendering conspicuous service to scientific record, education, and research. But the main duties of the Geological Survey remained with it, and have been carried on for a century. These are to map the geology of the country on the largest practicable scale, to describe and interpret the structure of the land, to preserve the evidence on which conclusions have been founded, and to illustrate for students and other workers the geology of the country and its applications to economics and industry. The broad detail of the structure of the whole country is now known, but much new work must be done to keep abreast of or to lead geological thought. For instance, the study of the cloak of "superficial deposits", which often cover and conceal the structure of the more solid rocks below, is essential for the proper understanding of soils and agriculture; and a knowledge of the deep-seated geology of the country, which is often widely different from that nearer the surface and thus very difficult to interpret, is vital to the community for the successful location and working of coal and iron, and for tracing supplies of water and oil and other resources at depth.

Evolution of life on the earth has been by no means uniform; there have been periods of waxing and waning which may be attributed to geographical, climatological, and biological influences. The development of large land areas, ranged longitudinally or latitudinally, the invasion of epicontinental seas, the isolation of mediterraneans or inland seas, the splitting of continental areas into archipelagos or the reunion of islands into continuous land, the making of barriers by the rearing of mountain chains or the formation of straits or arms of the sea, the oncoming of desert or glacial climates; all such factors and many others have been of importance in quickening or checking competition, and in accelerating or retarding the evolution of life.

Probably, however, even greater effects have followed the interaction of groups of biological changes on one another. As an instance I might recall Starkie Gardner's estimate of the results following upon the first appearance of grasses in the world. This seems to have been not earlier than Eocene, and probably late Eocene

times. By the Oligocene they had made good their hold, peculiarities in their growth and structure enabling them to compete with the other vegetation that then existed; and gradually they spread over huge areas of the earth's surface, formerly occupied by marsh, scrub, and forest. They have, as Ruskin says, "a very little strength . . . and a few delicate long lines meeting at a point . . . made, as it seems, only to be trodden on today, and tomorrow to be cast into the oven"; but, through their easy growth, their disregard of trampling and grazing, and by reason of the nourishment concentrated in their seeds, they provided an ideal and plentiful source of food. On their establishment we find that groups of animals, which had previously browsed on shrubs and trees, adopted them, with consequent alterations and adaptations in their teeth and other bodily structures. To follow their food from overgrazed or sun-scorched regions they required to be able to migrate easily and quickly, and it was essential for them to discard sedentary defense and to flee from threatened danger. Such defense as was possible with heels, teeth, or horns, they retained; but the dominant modifications in their organization were in the direction of speed as their most vital need.

Side by side with this development, and in answer to increasing numbers, came bigger, stronger, and speedier carnivores, to feed on prey now so much more abundant, but more difficult to catch. The answer of the grass-feeders, with their specialized hoofs, teeth, and bones, better suited to flight than fight, was to seek safety in numbers, and thus develop the herd instinct, with its necessity for leadership and discipline; but this, in turn, provoked a like rejoinder from some types of their enemies.

When it is remembered how much of the meat and drink and life of mankind is bound up with the grasses, including wheat, maize, millet, and other grains, sugarcane, rice, and bamboo, we must realize how close is his link with the development just outlined. Practically his whole food supply is provided by them, either directly by the agriculturist who grows little else but grasses, or indirectly by the herdsman whose domestic animals are fed chiefly on the same food. Nor must we forget that almost every one of our domesticated animals has been derived from the gregarious types just mentioned, which have accepted the leadership of man in place of that of their own species.

It is perhaps not too much to say that the magnificent outburst of energy put out by the earth in the erection of the Alps, Andes, and Himalayas in Tertiary times was trivial in its influence for man's advent and his successful occupation of the earth in comparison with the gentle but insidious growth of "mere unconquerable grass" and

its green carpet of "wise turf" which in some form clothes by far the greater part of the land of the globe.

The kind of developmental reaction of which this is but a single example must clearly have had influence on bodily features other than bones and horns, teeth and claws, speed and strength; and one of the most striking has been on intellectual development and the size and shape of brain.

We do not, and perhaps can never, know the quality of the material of which the brains of fossil creatures was made, for we have no instrument to pierce the veil of time as the spectroscope has penetrated the abysm of space. But we are even now learning something about their shapes and convolutions, and more about their mass in its relation to the size of the bodies controlled; from the time of the earliest Ordovician fishes, through the history of the amphibia, reptiles, birds, and mammals, up to man himself.

The brain of those gigantic if somewhat grotesque reptiles, the dinosaurs, the tyrants of Mesozoic time, is relatively tiny. In Diplodocus, 80 feet in length and 20 tons in weight, the brain was about the size of a large hen's egg. It is true that there was a big supplementary sacral ganglion which may have taken chief charge of locomotion and helped to secure coordination throughout the hinder part of its huge length and bulk; but of true brain there was not more than a quarter of an ounce to control each ton of body and limb; and we begin to understand why they lost the lordship of creation.

The proportion of brain to body improved in those reptiles which took to flying, possibly in relation to their acquisition of warm blood, and in the birds evolved from reptiles; but it is only in mammals that a marked advance is seen. Here the brain of Uintatherium, a great rhinoceroslike animal of Eocene date, weighing 2 tons, was about the size of that of a dog. This proportion of half a pound of brain to each ton of body shows how far the mammals had gone, and still had to go.

A 12-stone man of the present day has about 3½ pounds of brain—an amount not far short of half a hundredweight per ton.

Even though we can know nothing of its material, this steadfast growth in the guiding principle, through the millions of centuries that have gone to its development, is surely one of the most remarkable conclusions that we owe to geology. Of all the wonders of the universe of which we have present knowledge, from the electron to the atom, from the virus and bacillus to the oak and the elephant, from the tiniest meteor to the most magnificent nebula, surely there is nothing to surpass the brain of man. An instrument capable of controlling every thought and action of the human body, the most

intricate and efficient piece of mechanism ever devised; of piercing the secrets and defining the laws of nature; of recording and recalling every adventure of the individual from his cradle to his grave; of inspiring or of ruling great masses of mankind; of producing all the gems of speech and song, of poetry and art, that adorn the world, all the thoughts of philosophy and all the triumphs of imagination and insight: it is indeed the greatest marvel of all.

And when we contemplate the time and energy, the sacrifice and devotion, that this evolution has cost, we must feel that we are still far from the end of this mighty purpose: that we can confidently look forward to the further advance which alone could justify the design and skill lavished on this great task throughout the golden ages that have gone.

CORE SAMPLES OF THE OCEAN BOTTOM

By Charles Snowden Piggot

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[With 6 plates]

If one examines a map of the world, or a globe, the most noticeable feature is the preponderance of water to land. In fact, the ocean occupies 72 percent of the surface of the earth—nearly three-quarters—and very little is known of it by comparison with our knowledge of the land. Geologists and others have studied the land and what lives on it so thoroughly that we now have reliable knowledge of its history, and the many changes that have taken place, both in the land itself and the plants and animals that lived on it, throughout many millions of years. These studies have been of great value both theoretically and practically and they are being continued with increased application. But all this time nearly three-quarters of the earth's surface has remained almost unknown and unstudied, because it lies below great depths of water. At one place the water is 6 miles deep. Here the bottom lies below us deeper in the sea than Mount Everest rises above us into the sky. Though much of what is now dry land was once below the surface of the ocean, it appears that the water covering it was never very deep. Though the sediments themselves might be many thousands of feet thick they were deposited layer on layer in shallow seas. Apparently, much of the bottom of the ocean has always been ocean bottom, and during all those millions of years that the ocean has existed there it has been accumulating the sediments dropped upon it from the waters above. These sediments, lying layer upon layer in the bottom, have become the repository of the historical record of the ocean. The record of what happened in the water above is filed away in the mud and clay and ooze below. The rocks and pebbles and sand brought by ice, the clay and mud brought by rivers and ocean currents, the skeletons of marine organisms which lived and died and evolved into various forms throughout the ages constitute this record. Some types of these organisms live only in cold water, others in warm water, some live in shallow lagoons, others in the depths of the open sea. Some prefer fresh water while others survive only in salty water. Some lived a long time ago, and others have evolved into their present

forms comparatively recently. Besides these records of past life and its many changes there exist a chemical and a physical record. Oxidation and reduction and the nature of the dissolved matter in the water have all left the record of their changes in the bottom, and the nature and size of the minerals and rock fragments bear evidence of the direction and strength of former ocean currents, the movements of ice, and the depths of the ocean in the past.

Although this great historical record has long been known to exist, we have been unable to profit by it, for we could read only the topmost page. Heretofore, the samples obtained from the deep ocean bottom have been "grab samples", a mere handful of material taken from the very surface of the bottom. These samples give information of present conditions only and reveal nothing of past events.

On land the geologist can study the exposed rock strata, he can climb mountains and descend into mines, and he can study samples from test borings and deep wells. Millions of such studies have been made of the land, and a very reliable knowledge of its geologic history has been assembled, but a similar study of material lying beneath miles of water is enormously more difficult. Far out from land, in the undisturbed depths of the open ocean, the record has accumulated very slowly, so that a few feet of depth may represent a very long interval of time. Therefore if we could bring up a vertical section of several feet of this bottom, in its original, undisturbed condition, we might read the history of oceanic events as the geologist deciphers the record in the rocks.

The need of such samples has been felt for many years and many devices to secure them have been tried. Recently an apparatus has been developed which has obtained such "cores" up to 10 feet in length and containing sufficient material for very comprehensive studies.[1] These cores have been brought up from ocean depths of 2,650 fathoms, which is more than 3 land-miles down.

The apparatus is self-contained and may be attached to any existing sounding line strong enough to lift it. It functions automatically on reaching the bottom and consists essentially of a steel tube (inside which is a brass tube) which, on arriving at the bottom, is forced into the sediment by an explosion of cannon powder contained in a weight or "gun" attached to its upper end. When brought to the surface the sample is held inside the brass tube, which is slipped out and labeled, and another tube put in its place ready for another sounding. The sample remains undisturbed in its brass tube until opened for examination in the laboratory.

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[1] Piggott, C. S., Apparatus to secure core samples from the ocean-bottom. Bull. Geol. Soc. Amer., vol. 47, pp. 675–84, May 1936.

The value of these samples, over previous ones, is that the material is available for study in the undisturbed sequence existing in the bottom, and consequently a record of succeeding events may be obtained from it. Particular strata may be traced over wide areas, and a knowledge of the succession of events in terms of time and extent may be obtained.
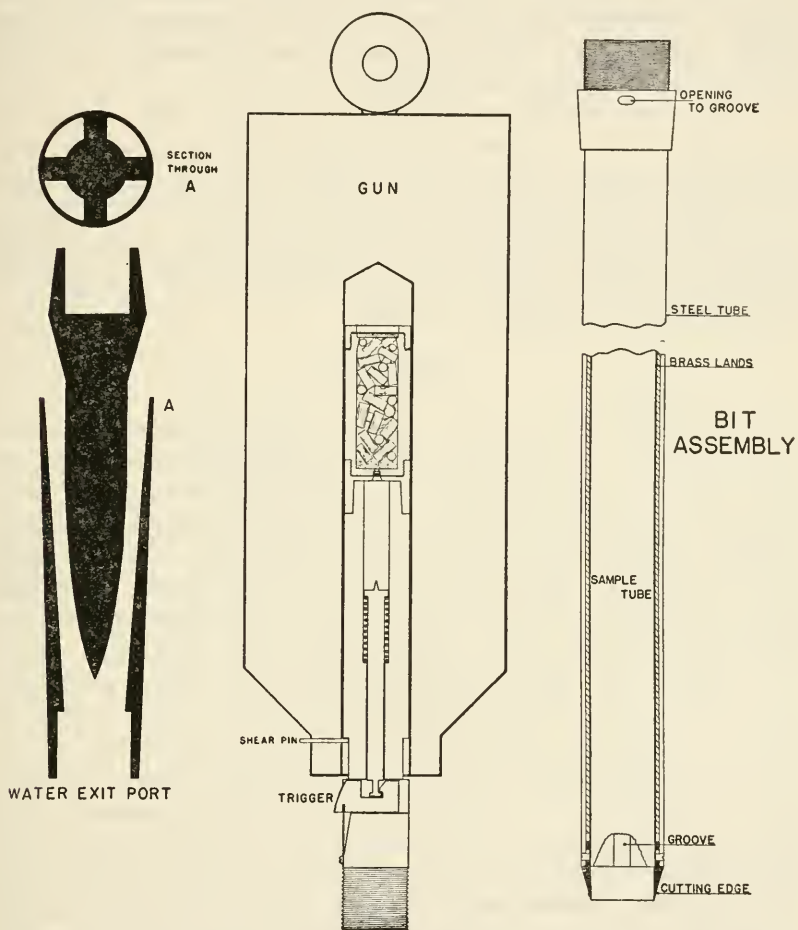
FIGURE 1.—Diagram of core sounding apparatus showing parts drawn to same scale.

DETAILS OF THE APPARATUS

The apparatus consists of five principal parts: a weight or "gun", a cartridge, a firing mechanism, a water-exit port, and a bit. These are shown diagrammatically in figure 1, and the assembled apparatus, with a 10-foot bit, in plate 1.

The weight is made of cold rolled steel, 10 inches in diameter and 20 inches long. At its upper end is a 1-inch drop-forged eyebolt, to which is spliced a steel cable (⅜-inch diameter) 4 feet long. A self-releasing hook may be placed here if it is desired to leave the weight on the bottom. The other end of the cable is spliced to a ring of drop-forged steel, about 3 inches in diameter. This ring constitutes the upper end of the apparatus, and it is at this point that the ship's sounding cable is attached.

The lower end of the gun is tapered to within 1 inch of the muzzle, causing the gun to have a 1-inch-thick wall for that length. One inch from the muzzle are four holes, drilled radially, through which a one-eighth-inch brass shear-pin may slip easily. The bore of the gun is the only part that must be made with precision. This must be reamed straight and smooth and must furnish a snug sliding fit for the cartridge and firing-pin housing.

CARTRIDGE

The cartridges (pl. 2) are made of stainless steel and are exactly 2 inches in diameter and about 4¾ inches long. They consist of three parts—a midsection, which is the powder chamber, and top and bottom sections. Both ends of the midsection have small circular ridges, which cut into copper disks and assure a tight seal. The walls of the powder chamber are one-quarter inch thick, and its bottom contains a recess into which a rifle primer fits exactly. Over this is placed a copper disk, against which the bottom section screws tightly. In the center of this bottom section is a small hole, opposite the primer, through which the point of the firing-pin may strike the copper disk with sufficient force to distort it and thereby set off the primer. This primer disk, however, is thick enough to prevent distortion of the primer by the hydrostatic pressure of the water. It is also made thick enough to have sufficient strength to prevent the primer from being blown backward out of its seat at the moment of firing. Furthermore, the thickness of this primer disk is so adjusted, with respect to the shape of the firing-pin point and the strength of the firing spring, that the point will distort it enough to fire the primer but will not punch a hole through it. When functioning satisfactorily the blunt-pointed firing-pin punches a dome-shaped depression in the copper disk sufficiently deep to fire the primer, and then this dome has enough strength to support the primer in its position against the high pressure of the main explosion.

Inside the muzzle end of the powder chamber is an annular shoulder, one-eighth inch from the muzzle. On this shoulder rests a steel disk, one-eighth inch thick, with its outer surface flush with the end of the powder chamber. Its function is to take the strain of the hydrostatic pressure and thereby prevent distortion or breaking of the rupture disk. Between the pressure disk and the rupture disk is a thin copper disk, which serves as a gasket. The rupture disk is of steel and of such thickness and strength that it will allow the pressure within the cartridge to build up to the proper working pressure before it ruptures and releases the energy to the mechanism.

POWDER CHARGE

The explosive charge furnishes the energy required to do the necessary work. This varies with the depth and the character of the bottom. The charge consists of a primer, 1 gram of high-speed black powder, 1 gram of rifle powder, and a varying number of pellets of 155-mm howitzer powder. The 2 grams of small powder play the double role of promoting ignition and quickly building up a pressure, in which environment the large-grained powder functions explosively. If this high pressure were not provided, the latter would not burn properly.

The total available energy is regulated by counting into the cartridge a varying number of pellets of the big powder. This required energy is of three parts: (1) That which is necessary to overcome the hydrostatic pressure at a particular depth; (2) that which is necessary to overcome the inertia of the bit and to put it into motion; and (3) that required to drive the bit into the particular material encountered. Only the second can be determined in advance; the other two must be provided for at each sounding. The possible work that can be done is a combination of the total available energy and an intensity factor—i. e., the pressure at which the explosive gases are released. The control of this "working pressure" is accomplished by the steel rupture disk at the mouth of the cartridge. Up to the time this disk is blown out, the powder is protected from the water. These disks are relatively thin, and, therefore, capable of distortion, and at a certain depth the hydrostatic pressure might conceivably be greater than the desired "working pressure"—hence, the steel "hydrostatic pressure disk", which relieves the rupture disk of all strain and enables it to be adjusted to the requirements.

FIRING MECHANISM

The firing mechanism is simple and rugged and can be easily removed for cleaning or replacement. It consists of a trigger, which is

essentially a piece of steel, 2 inches by 1 inch by one-fourth inch, sliding in an appropriate keyway and containing a projection which catches the end of the firing pin when "cocked." A slight downward movement of the gun, on reaching the bottom, forces the trigger over and disengages the firing pin, which is pushed forward by a stiff coiled spring. The firing pin is streamlined at its forward end and is grooved longitudinally to facilitate the movement of water out of the space progressively occupied by the pin as it advances. This eliminates a cushioning of the blow by the water. The forward end of the pin contains a conical tip of appropriate size and shape to enter the hole in the base of the cartridge and explode the primer through the copper primer disk. A safety pin of hardened steel is so situated that it holds the firing pin back, in the cocked position, even when the trigger is disengaged, and even if the gun should be forced down and shear this safety pin off on the outside, that which remains would prevent an accidental discharge. As this safety pin is put in place before the cartridge is attached, a premature discharge, even under most extreme conditions, is almost impossible. After the apparatus is over the side of the ship, and just before it is lowered, this pin is withdrawn (by means of a lanyard, if desired) and the apparatus is thus "armed." Should it be necessary to return the apparatus to the deck, before firing, this pin can be inserted again before the apparatus is hoisted over the side.

WATER-EXIT PORT

Early designs contained ample openings in the walls of the bit tube at its top, and, should the bit be forced slowly into mud, the displaced water would flow out through these. But because of the high velocity of the bit, at the time of firing, the water within it acted as a solid body and did not yield space for the mud to enter. The ideal condition would be a bit tube completely open at both ends, which would then pass through the water and mud, leaving them both stationary. But a perfectly open top is not mechanically attainable because of the necessity of keeping the violent blow of the explosion accurately centered along the axis of the bit. Furthermore, this powerful blow must be mechanically carried to the walls of the bit tube. This necessitates rugged construction between the center axis and the outer walls. After much experimentation the open-tube ideal was very closely approached, by taking advantage of aerodynamic and wind-tunnel data and modifying the best curves in accord with the greater density of the water medium. The exit port somewhat resembles a nozzle in reverse. The inner walls slope outward along an ideal curve, and the center projection is so shaped that the cross-sectional area (hence, volume) available to the water is the same at any plane normal to the axis.

This is true up into that portion where the four steel webs carry the force of the blow from the center axis to the walls. Near the upper end of this part, the available volume increases slightly, and this fact, combined with the outward slope of the outside of the walls, provides a partial vacuum or cavitation—during the rapid movement through the water—which removes the back-pressure from the column of water inside the bit and provides an almost open-tube condition.

Though the bit was frequently driven deep into mud, no samples were obtained until this device was perfected.

THE BIT

That portion of the apparatus below the water-exit port has been called the "bit." Its length determines the possible length of the sample; bits of different lengths may be used as found desirable. It consists of a tube of alloy steel of $2\frac{1}{4}$ inches inside diameter and $\frac{1}{8}$-inch walls. Inside it are four longitudinal lands, as in a cannon, but straight. The four grooves between these lands communicate with four openings to the outside at the top of the tube. Their function is to permit water to get down to the bottom of the bit and to fill the cavity in the mud created by the withdrawal of the bit—i. e., to "break the suction." The brass sample tube slips inside the lands and fits snugly against them; this causes the grooves to form longitudinal channels from the top to the bottom of the bit.

The bottom edge of the bit is provided with a cutting edge of hardened tool steel, which fits loosely between the sample tube and the steel tube and is prevented from falling off by two small screws. However, it has a play of three-sixteenths inch—i. e., may hang that far below the end of the steel tube—but when pressed up it fits snugly against the end of this tube. It therefore acts as a valve, which prevents mud from entering the grooves while the bit is being driven into the bottom, but opens and permits water to flow out of the grooves while the bit is being withdrawn from the mud.

After a "shot", the brass sample tube is withdrawn, with the mud core inside it, and a new one is inserted. It is cut off at the top of the mud, corked at both ends, and these corks securely taped. They are labeled in a manner to indicate the top and the bottom of the core and may then be shipped and kept without alteration until opened for examination in the laboratory. This is done by cutting the tube longitudinally in two diametrically opposite places and then inserting two sheets of tin in one slot and pressing them across to the opposite wall. The tube may then be opened hinge-fashion and the tin strips removed without distorting the sample. This produces two equal parts to each sample, each part lying in its own brass trough, and reveals the structure of the core. This procedure

provides an undisturbed half for control or future reference; the other is used for investigation. Furthermore, the undisturbed half provides a depth scale, from the surface downward, which is of considerable value. It has been found convenient to split the half to be examined, either in half again or into quarters. This is done with each fragment individually, using a thin-bladed hacksaw or its equivalent. The fragments may always be returned to their proper place in the brass trough.

<div align="center">SOUNDING PROCEDURE</div>

The procedure on shipboard was to fasten securely to the deck, at a convenient place, a strong board. This was made straight and flat by suitable wedges, and to it were fastened prepared chocks to hold the gun, and also several chocks to hold the bit. These are so made that, when the assembled apparatus is laid in them, the bit and cartridge are lined up with the center of the bore of the gun. If such guides are not provided, the small clearance between the gun barrel and the cartridge assembly makes it exceedingly difficult to push the latter into the gun.

The apparatus is assembled in the chocks, the firing mechanism cocked, and the safety pin inserted. A cartridge is loaded in accord with the anticipated need. If it is the first sounding in a new locality, it is advisable to provide rather less than the anticipated required energy. Subsequent loads may be increased as circumstances warrant. When all is ready, the cartridge is fastened in place and the gun "loaded", by sliding the bit toward the gun, and the shear pin is put in place. The apparatus is then hoisted over the side. A man picks up the bit at the cutting edge, and, as soon as the gun clears the rail, he drops his end over the side into the water. The apparatus is immediately lowered until only the gun is out of the water; this prevents swinging against the ship's side. Finally, the safety pin is pulled out and the apparatus is lowered to the bottom. With shallow soundings the explosion can be heard and felt on the ship, and with deeper ones it can also be picked up by a microphone or the ship's sonic sounder. Where these failed to give any indication, the cable was paid out until more than the anticipated depth was out, and then the apparatus was hauled to the surface again. If it has fired, the gun and bit will be hanging separately at the end of their respective cables, the bit supported in the stirrup. If they are not so separated, and it is desired to bring the apparatus aboard, the safety pin must be inserted at the earliest possible moment while the apparatus is hanging clear of the ship. Once this pin is in place the apparatus may be brought aboard with safety.

If the apparatus has fired, the gun is hoisted up until the bit can be gotten over the side; this is laid in its proper chocks, and the gun then lowered to its chocks.

Sixteen soundings were made at sea in August 1935, yielding the 14 cores shown in plate 3, figure 1. One failure was due to a defective primer, and once the core pulled out. The 14 cores vary in length from 4 feet to nearly 9 feet and are solid throughout. The depths of these soundings varied from 200 fathoms to 1,250 fathoms.

The 11 cores shown in plate 3, figure 2, were obtained during May 1936, between the Grand Banks of Newfoundland and the edge of the continental shelf west of Ireland. Seven of them are from depths greater than 2,000 fathoms and all the remainder but one from more than 1,000 fathoms. The one exception is from the top of the Faraday Hills at 700 fathoms. The greatest depth was 2,650 fathoms. The very short core contains several inches of rock.

Plate 4 shows these cores split open ready for study, arranged, as taken, from west to east across the North Atlantic, and plate 5 a more detailed view of some of them showing the stratification and change of character of the material.

The cracks are due to drying. This can be prevented by keeping the cores in a saturated atmosphere, but since the dried segments leave marks on the brass troughs which establish their positions from the surface this is not usually done.

DISCUSSION

These samples are of interest to many investigators. The marine biologists and micropaleontologists will find in them the remains of marine organisms which lived ages ago in the waters above. These organisms will change in character, from level to level of the core, reflecting their evolutionary development and the changes of type brought about by changes in the temperature of the water. Thus it may be possible to state that throughout a certain period in the past the water was much colder, or warmer, in that portion of the ocean. Or they may show that it was shallower—a mere lagoon, or deeper. The sedimentologist by a study of the minerals and the size of the particles of rock will be able to trace the changes of direction and possible force of ocean currents throughout past ages. The character of the sand and pebbles will indicate the presence of ice or the proximity of land where only ocean exists today. No one of these bits of evidence will be conclusive in itself, but many taken together may build up a strong corroborative presumption of a certain condition.

Some chemical and mineral constituents are of great significance, as for instance the fluorine and chlorine and other acid or basic radi-

cals; also the metals such as manganese and iron, which are often found in great concentrations, or those which are found in extremely small concentrations, such as copper, tin, gold, selenium, or radium. The radium is of particular interest and significance because its concentration in ocean-bottom sediments has recently been found to be, in general, much greater than in either igneous or sedimentary rocks on land, and this difference is as yet not completely explained. The concentration is greatest in those portions of the ocean bottom more remote from land and lying at the greater depths. The material at the bottom of the deeper parts of the ocean generally consists of so-called red clay, and this material appears to contain much more radium than any rocks yet examined on land. If these sediments are of considerable depth, and if this radium concentration is the same throughout, these deeps constitute local concentrations of radioactive material possessing enormous stores of energy. Since we have found no sedimentary rocks with radium concentrations remotely approaching those existing in these sediments it might be inferred that the many changes of level of various parts of the earth's surface have nowhere brought up an ocean deep. It may be that the deeper portions of the ocean are permanent features of the earth, or else it may be inferred that this high radioactivity is but a transitory thing, representing the activity of radium only, unassociated with its long-lived parent substance uranium. If this be so, the nature and cause of its separation and concentration from sea water would be a most important study. Furthermore, a study of the radioactive substances and their disintegration products in these cores holds a promise of a determination of the time intervals represented by the various strata, or the age of the sediment as a whole. This in itself is of the utmost geophysical and oceanographic significance.

The only record of the history of the existing ocean lies buried in its bottom. Whether this record will be easy or difficult to decipher, voluminous or meager, remains to be ascertained, but whatever its nature it is now accessible to us through the medium of these core samples.

PLATE 1

THE CORE SOUNDING APPARATUS ASSEMBLED READY TO LOWER.

PLATE 2

FIRING MECHANISM

WORKING CHARGE: CANNON POWDER

FLASHING CHARGE: BLACK AND RIFLE POWDER

FIRING PIN AND SPRING | TRIGGER
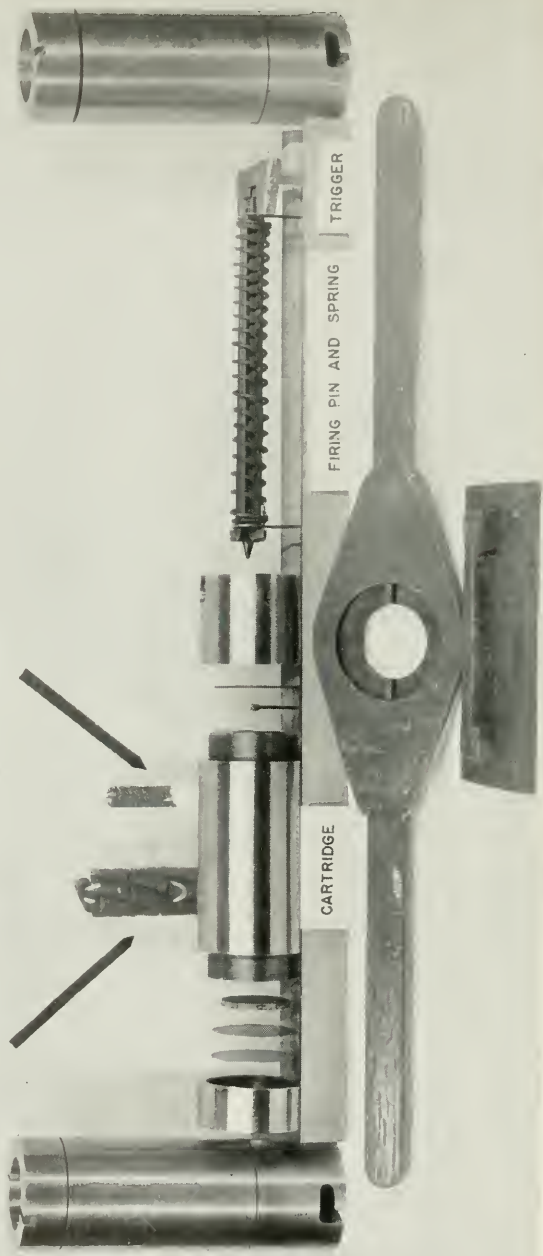
CARTRIDGE

CARTRIDGES, FIRING MECHANISM. POWDER CHARGE. CONSTITUENT PARTS AND WRENCHES.

PLATE 3
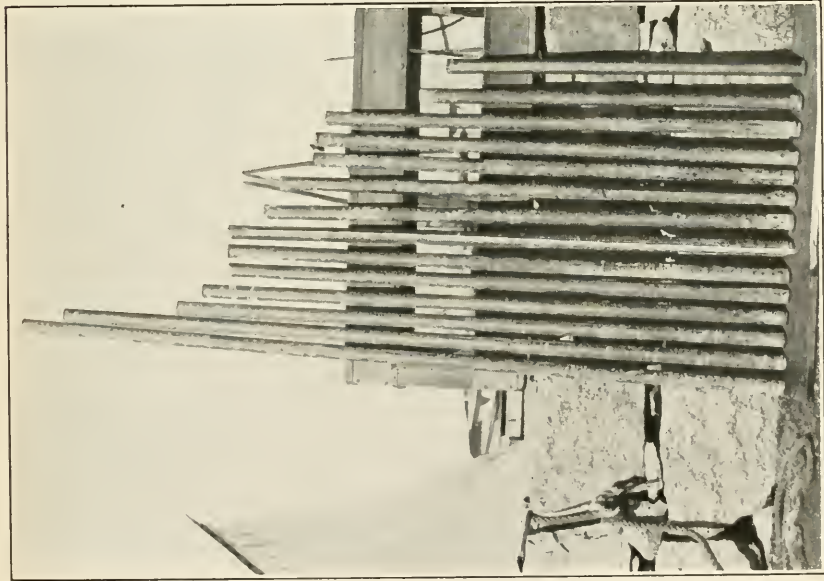
1. CORES TAKEN FROM SUBMARINE CANYONS OF ATLANTIC COAST.

Depths of 1,200 to 7,500 feet. Longest core 8½ feet.
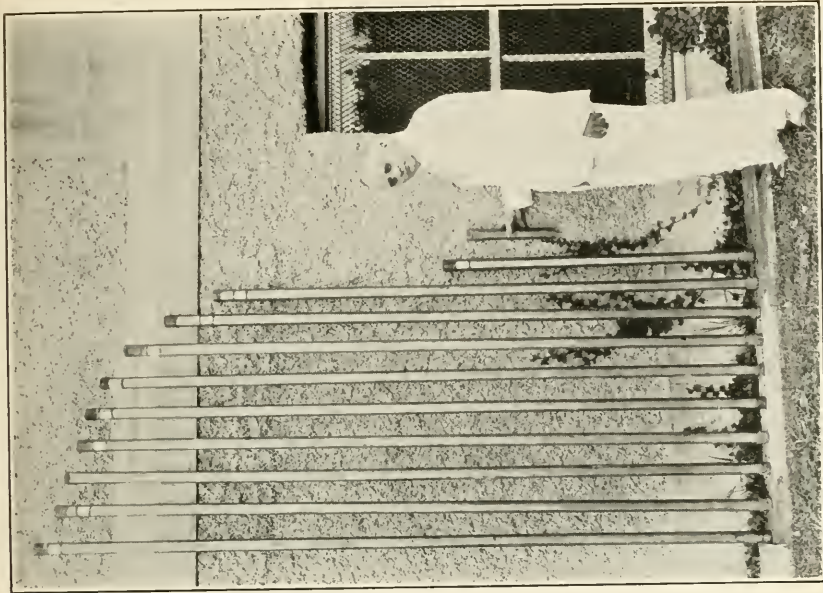
2. CORES TAKEN ACROSS NORTH ATLANTIC OCEAN BETWEEN NEWFOUNDLAND AND IRELAND.

Depths of 4,200 to 15,000 feet. Longest core 10 feet; shortest contains some rock.
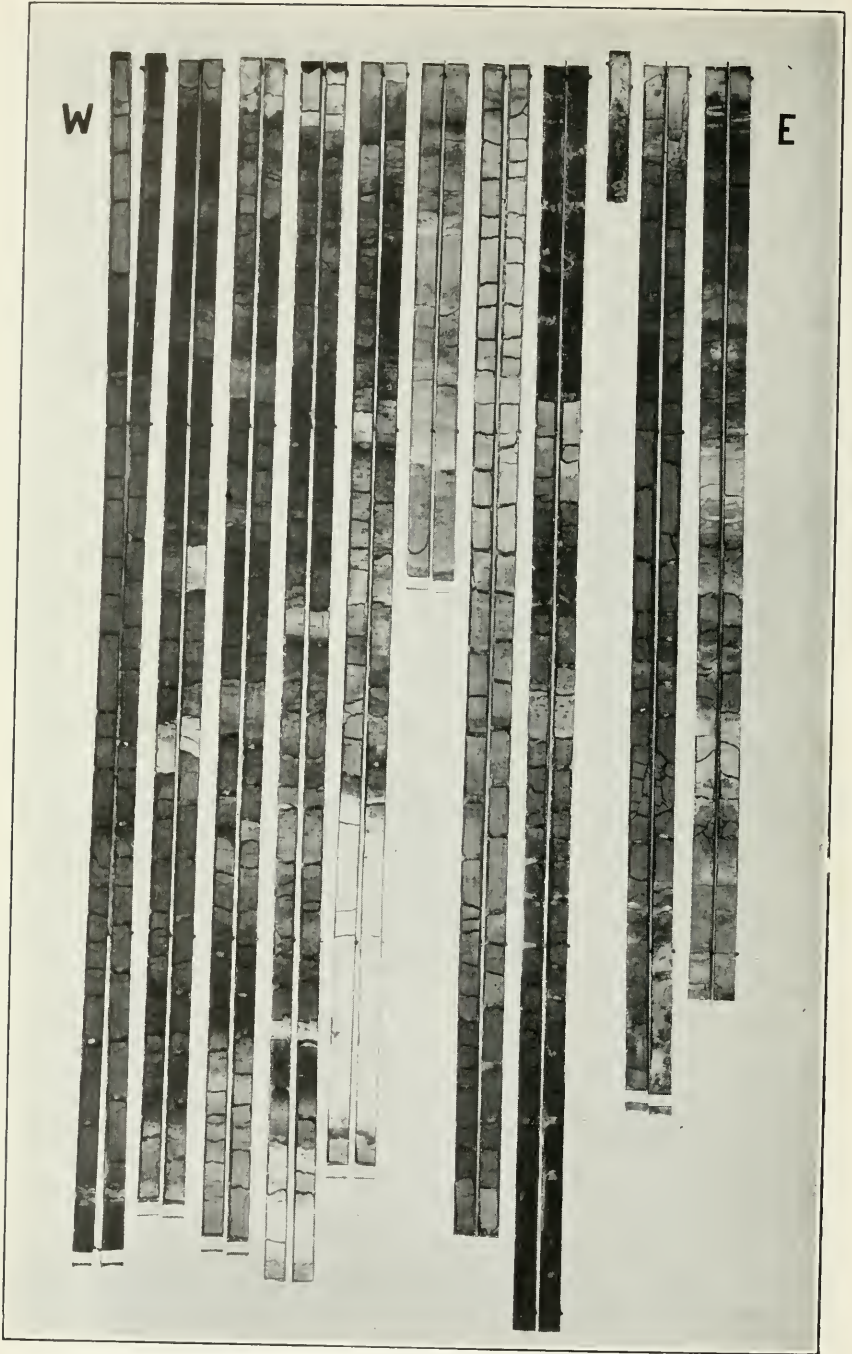
PLATE 4

NORTH ATLANTIC CORES SPLIT OPEN.

Arranged as taken from west to east.
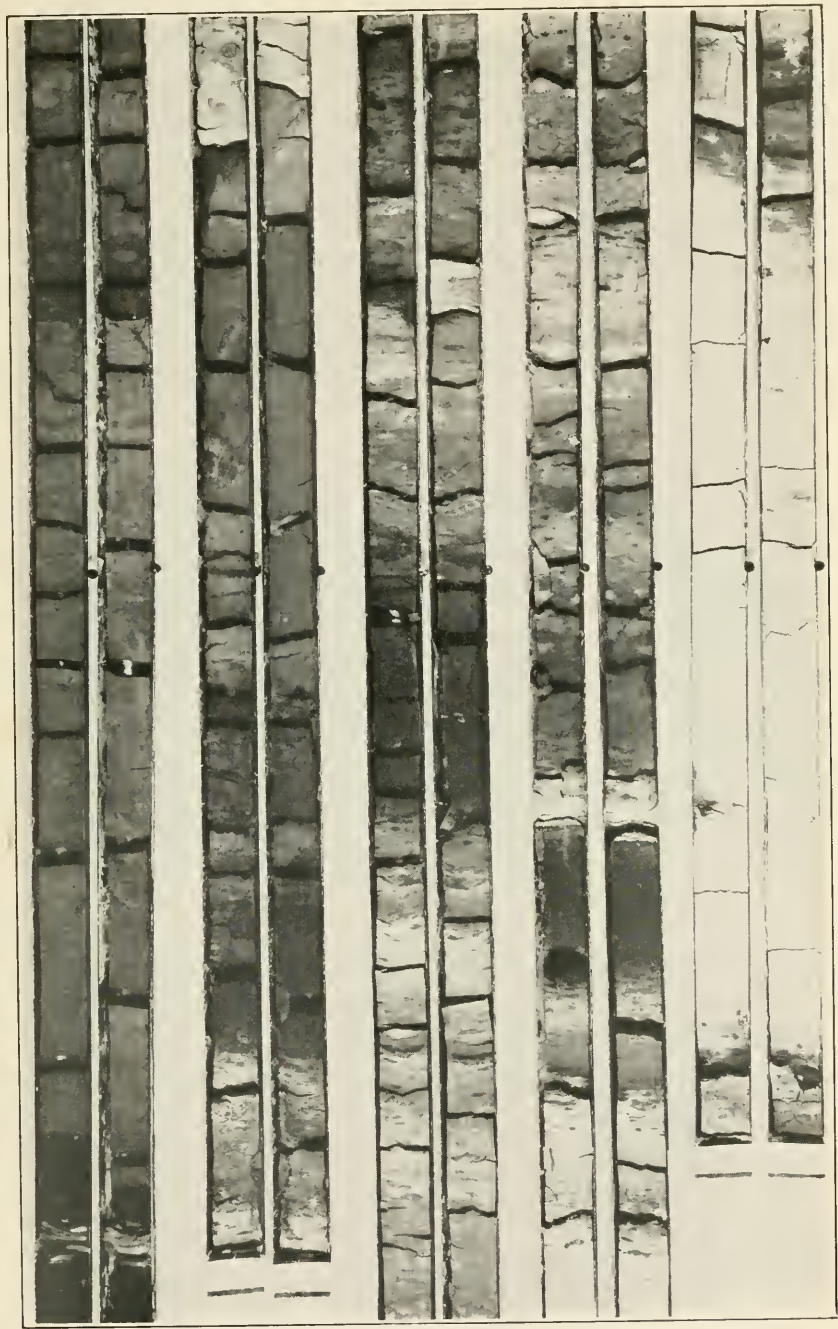
PLATE 5

ENLARGED VIEW OF PART OF PLATE 4.

PLATE 6

1. APPARATUS JUST OVER THE SIDE.

Sailor near camera has just thrown cutting edge clear of rail. *Atlantis*, August 1935.
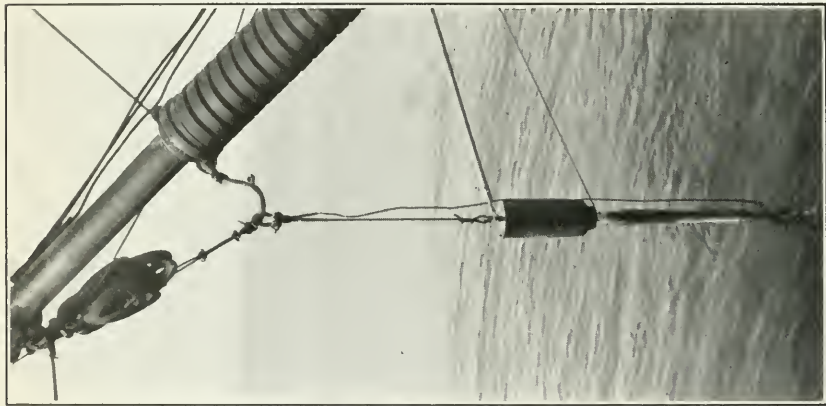
2. APPARATUS ABOUT TO BE LOWERED ON SHIP'S SOUNDING CABLE.

Safety pin being pulled by means of lanyard. *Atlantis*, August 1935.

3. BIT BEING BROUGHT INBOARD OVER THE RAIL AFTER A SOUNDING.

The cartridge has been removed from upper end (to forestall possible loss). Waterport is wedged in ring of "stirrup." *Atlantis*, August 1935.

SOME NEW ASPECTS OF EVOLUTION [1]

By W. P. Pycraft, F. L. S., F. Z. S.

[With 6 plates]

It may be that I am expected tonight to say something about the fauna, or the flora, of Norfolk, or of both; but abler men than I in this chair have already well-nigh exhausted these themes. Yet, what I am going to say has indeed a bearing on both, though it refers by no means especially to the natural history of our beloved country. What I would call the first installment of a new, and more intensive study of this history has been given us in that most inspiring volume recently issued by this society, on the work which has been done at Scolt Head Island. It was a model of what such investigations should be; and some may think that the last word in this connection, so far as Scolt Head is concerned, has been said. But I want to convince you that really no more than the foundation has been laid for a much wider conception of what is taking place, not only here, but wherever animal or plant life exists.

I was particularly interested in what was said in that volume on "environment" because, it seems to me, that its importance has been overestimated, both by zoologists and botanists.

If we are to make any real progress in our search for what I will, for the moment, call the "ferment" which finds expression in the evolution of the different types of animals, and of the evolution as well of species, we must dare to question the faith that is in us in regard to that part which we are told is played by "environment." We have come to use this word with the same assurance as the naturalists of a generation ago used "natural selection." Let me hasten to add that I do not wish to imply that natural selection is dead; that is by no means true, but we loaded on to its back more than it ought to have been asked to bear. It was, and most unreasonably, regarded as the key to the mysteries of evolution. When, at last, it was realized that this was not so, new trails were taken up, as if in the hope that,

at last, some theory would be found that would explain everything. That is a vain hope. There are many factors in evolution, and natural selection is one of them; environment is another. But the case for environment seems to require revision. At present the term is too vague, and I venture to hold that many structural peculiarities of plants and animals have wrongly been attributed to "environmental influences." Perhaps the most plausible examples of these "influences" are those furnished by the deep-sea fishes.

But before I go further let me endeavor to make my meaning clear on this theme. What is "environment"? What do we mean by the term? If we are to form any helpful conception of what is implied thereby we must go back to the primeval conditions of the world, before the advent of life on its surface.

When the process of cooling began that surface was already irregular, broken up by deep valleys and deeper basins. With the advent of "rain" the water was gathered up in the valleys to form rivers. And as they ran down into the basins, eventually filling them to become "seas", they carried down, in solution, various salts derived from the disintegration of the rocks over which they passed. Hence the saltness of the sea.

Then came the formation of "colloids", and the origin of "life", which started probably in the shallower waters of the sea. This "colloid" substance, being unstable in its qualities, began to assume different forms of primeval plantlike organisms which gradually extended their range seaward and landward, and ever assuming new forms, in accordance with the nature of their assimilative powers, "selecting" different ingredients of the "soil" formed by this disintegration of the rocks just referred to.

The dawn of animal life, dependent for its sustenance on organic food material furnished by these primeval plants, started later, and developed, like the plants, in accordance with its assimilative and selective powers, which were ever extending. Both these types of living matter began with, and maintained, an inherently increasing complexity of structure, evolving "individuals" more and more committed to a definite line of development, in accordance with the nature of the substances taken in as "food", and the nature and qualities of the materials fashioned from it as the result of the metabolism of these several individuals.

Here we might speak of two "environments", water and land. But is there any evidence that these living bodies, still of the simplest types, were fashioned by the "environment"? Already, it is true, some had advanced so far in one direction as to be unable to live out of the water, while some were similarly unable to live in the water. But the several groups of individuals thus come into being did not owe their several peculiarities, whereby they could be distinguished

one from another, to their "environment", but, as illustrated in the case of Penicillium (p. 221), to their "chemotaxic" qualities, and the nature of the "tissue" resulting from their metabolism, which made different tissue out of the same food material. Each addition to the structural complexity in these different individuals, living in these now mixed communities, was an addition made in the processes of repairing waste during the activities of the body, the areas most stimulated by work taking up most of the products of digestion. Thus began the evolution of the myriad forms of life which have come down through the ages till now.

In other words, the necessary movements made in the search for food, and the necessary reactions for the digestion and assimilation of that food, brought about responses and reactions of the tissues of the body of ever-increasing divergence as the different types evolved—algae, bacteria, fungi—and so on to flowering plants and trees; the Protozoa, Coelenterates, and so on, to man himself.

Some of these, like the mole, the cetacea, the sloths, to take but a few random examples, have become highly "specialized", and committed to a restricted amplitude of activities. And such are commonly supposed to have been molded by their "environment" and not by their "proclivities."

Doubtless environment is a factor in evolution, but the precise part which it has played, and is playing, has yet to be defined. Parasitic Protozoa, worms, and Crustacea like *Sacculina*, and some Cirripedes, may possibly be set down as cases of "environmental adjustments." And the deep-sea fishes are in like case.

Today there are many who still, unfortunately, regard such and such an animal or plant as if it were merely a complex of tissues forming the various parts or organs which make up its body, and to regard these tissues, furthermore, as curiously and mysteriously unstable, so that variations and permutations are always to be expected and always to be regarded, not so much as "fortuitous", as in some intangible way brought about by changes in "environment", giving rise to qualities, and changes, which endow that body with an enhanced power of meeting the conditions of that environment, animate or inanimate. So long as we accept this interpretation as the mode of evolution, so long shall we fail to understand the mysteries we are professedly trying to solve.

Organisms, simple or complex, from amoeba to man, are not the sport of chance variations after this fashion, dragooned, and "licked into shape" by external conditions. They, in short, are not to be regarded as so much clay molded into shape by the great potter, "environment." Rather, we are to regard the various types of animals as self-regulating organisms, molded by the effects of the persistent stimuli sustained by their several organs, or parts of

organs, which thus become shaped by use, in the higher animals, under the controlling agency of the sympathetic nervous system. But inasmuch as living tissue is in no two organisms precisely alike in its qualities, it follows that this "use" will manifest itself in different ways, even when the conditions under which they exist appear to be the same.

Plants and animals differ from inanimate things in that they grow from within, by a process of "intussusception", and not from accretions from without, as in a crystal. Now this growth, in living tissue, is made possible by taking up substances external to the body, and in some mysterious way converting them into living tissue. The plants can extract this life-forming material from the mineral world, but animals can only obtain it from other organic bodies, living or dead. It goes, we say, to repair "waste." Let me cite an instance of this kind. One goes for a long walk, returning tired and hungry. After a good square meal, that stomach-hunger is appeased, and is followed by a sense of satisfaction. But there was also a muscle and nerve hunger of which the pedestrian, unless he were a physiologist, would not be conscious. Now that "good square meal", in a very short time, was reduced in the alimentary canal to a state resembling salad-cream, enabling it to be taken up by the lacteals, and passed, drop by drop, into the left subclavian vein at its junction with the internal jugular, and thence to be carried by the blood-stream to the tissues most in need of it—those wasted by the exertions of walking. They would take most of that "repair substance", the rest of the tissues of the body would absorb according to their need, and what was still to spare would be used up to form new tissues, or, as we say, to promote growth. And so it comes about that the tissues which are used most will take up most of what we call the "food material", growth being determined by the measure of use.

But in this process of growth, in course of time, the form of the whole body may become materially changed. And how this comes about I propose to show by examples chosen from many different types of animals. But I would first draw attention to another aspect of these tissues, for it is one of no small importance.

They display a curious power of "selecting" substances from their food, which give them qualities confined to particular species of animals, often closely related. Hence the different qualities and savors of beef and mutton.

Everyone must have noticed, in carving a grouse, that the upper layer of the two great breast muscles is conspicuously dark-colored, while the lower is white. In the pheasant both are white. We can, at present, assign no reason for this curious fact, which was manifested, not on the dissecting table, or by any process of analysis save

that of the kitchen oven.   Why should the products of digestion have brought about this singular "ear-marking" of these two breast muscles?

Let me give one more illustration, to which, indeed I draw your very particular attention.   A solution of racemic acid subjected to the plane of a beam of polarized light does not give the effect known as "polarization."   But if allowed to crystallize, rhombic, hemihedral crystals are formed.   These are asymmetrical, so much so that the crystals of one group are like mirror-images of the other group. Now if these crystals are dissolved separately, and the two solutions examined under this test, they exhibit what is known as rotary polarization, in the one case the plane is twisted to the right, in the other to the left.

But if instead of crystallizing the original solution the spores of the green mold Penicillium be sown in it, and that solution be then filtered, it will exhibit only left-handed rotary polarization.   The fungus has selected the right-handed moiety for the purposes of its growth, leaving as a residuum only that constituent of the solution which forms left-handed crystals.   Here, then, is a striking example of the subtle processes of distillation which living substances are capable of, in building up new tissues, either to repair waste, or to promote growth.   What part have "natural selection", or the "environment", played in any of these instances?

Now let me pass to survey the evidence which, so it seems to me, proves the immense importance of "use" as a factor in molding animal bodies, for of necessity I must exclude plants, though the same factors obtain here.

The persistent habit of burrowing, in some ancestral shrew gave rise at last to the mole.   The stimuli of persistent use, in one direction, caused those parts of the body more especially subjected to such stimuli to change their shape, but exactly in accordance with the peculiarities of the qualities of the tissue peculiar to the body of the mole. The marsupial-mole, an animal not even remotely related to our mole, has similarly transformed the fore limbs into digging organs, but they differ conspicuously from those of the common mole.

With these preliminary examples to show what I am driving at, and to enable you to follow me more easily, let me proceed to take a series of examples of different types of animals "in the making."   I will begin with the arboreal types (pl. 1).

Birds and beasts of many different kinds make their home among trees, as do others on the ground.   But some have become intensively arboreal, and this habit is always accompanied by more or less striking adjustments of structure brought about in response to the persistent and restricted use of the parts affected.   But these adjustments

are gradual. Let us take the case of the cuscus, one of the marsupials. Herein the fingers of the fore limb, when not grasping a bough, are comparable to those of the human hand. But as soon as a grip is taken of a branch, two fingers curl round one side, and three round the other side of the branch. Moreover, it has a long tail, and the lower half of this is hairless on its under surface, which is very sensitive to touch and can be used as an extra hand in gripping boughs. In the koala, another arboreal marsupial, the fingers of the hand have become permanently separated into a pair turned inward and backward, and three turned outward, while the tail has vanished. In the "anwantibo" (*Arctocebus*) and the potto, we get a stage further; in the former the index digit is but slightly developed, while in the potto it is reduced to a mere stump. The last word, so to speak, in this specialization for an arboreal life is found in the sloths, for these live permanently clutching the boughs of trees, suspended, back downward, by means of great curved claws converting the fingers into mere hooks. Finally we have the chameleon, wherein the toes of both fore and hind limb have become apposable, while the tail is prehensile. Here, then, are a number of animals belonging to totally different groups, which have, by intensive use, limited to one mode of locomotion, materially changed the form of their feet. Some have converted the tail into a prehensile organ and others have lost it. In both cases there is a direct association with the habits of the animals concerned and this enhanced function of the tail on the one hand and its loss on the other.

Now turn to the burrowers. If you were shown a rabbit for the first time and told that it was a burrower, the statement would seem absurd; for there is no indication whatever of such a mode of life in either the fore or hind limbs. And it would seem equally absurd to exhibit a sand martin, or a bee eater, or a kingfisher, and say they were burrowers. For they bear no structural evidence of this mode of activity. The reason is obvious. In none of these cases is burrowing more than an occasional incident in their lives. The rabbit must wander far in search of food, and be able to get swiftly home to its burrow when danger threatens; the martin and the bee eater seek their food in the air, the kingfisher in the water. Therefore flight is essential. But note that in all three the legs are extremely short, for they are never used save to grip branches when they come to rest. Their size bears a direct relation to the intensity of their use.

Now turn to the mole for a very different aspect of burrowing. This animal, it will be remembered, is one of the shrew tribe, which are also burrowers. But their burrowing does not absorb much of their energies, for they must find their food abroad. Hence, here

again, we have no structural evidence of burrowing. At some time in the remote past, however, the ancestral mole took to a diet of worms and to pursuing them, as well as grubs of many kinds, by driving tunnels under the ground. Hence, he was committed to digging for his very existence. And these intensive labors, be it remembered, fall with equal insistence on male, female, and young, and unceasingly. As a consequence of the persistent stimuli to which the fore limbs especially have been subjected, the characteristic shortening of the arm and forearm and the enormous hand, have come into being.

But, be it noted, there are many other animals in no way related to the mole, which have to dig for a living, and in each case the resultant modification of the fore limb is different. In *Notoryctes*, which is a marsupial and therefore a member of a totally different group of mammals, the general form of the body is singularly like that of our mole. But the fore limbs, though greatly shortened, do not show the great hand of the mole. The reaction to their use as digging organs has brought about an enormous enlargement of the claws. In no two animals, unless they be of the same species, will the same organ show precisely similar responses to the same kind of stimulus brought about by use, in this connection of digging. The armadillos, and the anteaters, have also forefeet shaped by persistent digging. But since they must live above ground, and not beneath it, the legs have not greatly changed from the type common to creatures which must walk, and run, to get a living.

Let me now turn to swimming. I have cited the rabbit and the sand martin as burrowers, which give no evidence of this habit either externally or internally. The water vole may be cited as a similar example among swimming animals. We can as easily account for this, as in the case of these burrowers.

But the hippopotamus affords us a peculiarly interesting example of the way "adjustments" are made where stimuli are intensive and persistent. And here they are found in the head. This animal passes the greater part of its life in the water, and can swim and dive with great facility, and remain long submerged. Look at its head, and note that the nostrils, eyes, and ears have all become raised above the general level of the skull, enabling the creature to breathe, see, and hear while the rest of the great body is submerged. But why do the limbs show no "adjustment" to this aquatic existence? The explanation is simple. These great beasts have to take long journeys overland, in search of fresh feeding grounds, and heavy strains and stresses are placed upon the limbs when the great body is no longer supported by the water. Hence, a large proportion of their "repair tissue" is absorbed to keep up the efficiency

demanded for walking. Not unless, and until, they were compelled to live permanently in deep water would the limbs undergo "adjustment" to swimming.

The sea lion shows us an advanced stage in the transformation of walking—into swimming legs. Though it still passes much time out of the water, all its food had to be obtained in the sea. Hence, intensive use of the fore limbs has slowly converted them into "flippers" differing from those of the Cetacea in that they still show digits externally, terminating in claws. But the hind limbs are also becoming greatly modified, so much so that they can do no more than enable the animal to "hobble" along, with the aid of the flippers, when on land. The seal carries us a stage further, for the hind limbs can no longer be turned forward to contribute to the support of the body when ashore. They are directed permanently backward, with their plantar surfaces apposed. The "flipper" in the case of the seals is never elongated after the fashion of the sea lion, and we must attribute this fact partly to the "intensity" of its swimming, and partly to the fact that here, as elsewhere, the response has been different because the "qualities" of the tissues forming the limb are different.

In the porpoise and the rest of the Cetacea, we find what we may call the "logical sequence" of a still more intensively aquatic life, which has profoundly affected the whole body. External hind limbs have now vanished, and the fore limbs have not merely become transformed into flippers but their internal structure has undergone a drastic change to which reference must be made again. The fishlike mode of life has brought about, with a few most interesting and important exceptions, a "dorsal fin", while the tail has developed horizontally directed "flukes", which have a very instructive bearing on this matter of "adjustment", as may be seen on plate 2. The Cetacea, being lung-breathers, must come periodically to the surface to breathe. The horizontal tail has been formed by the response of a once otterlike, cylindrical tail to the resistance of the water in using the tail to drive the body downward after food and upward for air, for these movements gradually started a flattening out of the tail, and its expansion into flukes. The fish, which has no need to come incessantly to the surface, drives the tail in a lateral direction, to impel the body forward, hence the tail fin is vertical. The manatee, be it noted, is in no way related to the Cetacea, yet it has assumed a similar form. The fore limbs have become flippers, there are no external hind limbs, and there are tail flukes as in the Cetacea. Moreover, in the river dwellers these flukes are spatulate in shape, but in the marine Steller's sea cow, now extinct, and the dugong (*Halicore*), they have the triangular form of the Cetacea.

The spatulate tail suffices for the still water, but life in the sea demands more strenuous movements, hence the change from spatulate to triangular.

Finally we have the case of the penguins. And these must be considered with the guillemots, and razor-bills, which, you will remember, use their wings as propellers under water. But these have not become "flippers", because they are used yet more intensively for flight, up to their breeding ledges, and down to the sea. The great auk lost the power of flight because it bred on low ground, which could be reached without the aid of wings. The decline in the size of the wings would probably have gone no further because they were needed as propellers. The penguins are still more intensively aquatic, and have no need for wings to carry them to nesting ledges on steep cliffs. Hence they gradually assumed the form of flippers, their size depending exactly on the measure of their use.

And now let me pass to a few cases which seem, so to speak, to "floodlight" the problem of "use and disuse", that is to say of effects of persistent stimuli concentrated on one organ, or part of an organ. These illustrate what I would call "reciprocity" in development, and are shown on plate 3.

There are some birds wherein the windpipe, for some mysterious reason, develops "hypertrophy." It grows too long for the neck. In the African black guinea fowl (*Guttera*), as a consequence, it forms a loop which came to be apposed to the hypocleidum—the flattened plate formed at the junction of the two clavicles, or "wish-bone." As a consequence of this contact, this plate first developed a thickened edge at the point of contact, which gradually expanded to form a cup, into which the loop is received. In some swans, and again in some cranes, a still more exaggerated lengthening of the windpipe brought about the formation of a loop which established contact with the anterior border of the keel of the sternum. This, as you know, forms a median plate running down the center of its under surface. It is formed of two thin layers of bone enclosing cancellated tissue between them. Now when the loop began to press, ever so lightly, against the front border, it "splayed out" to form a shallow trough. As the pressure steadily increased this trough deepened, forcing apart the walls of this keel, till, at last, a long tunnel was formed for the reception of this excess in the length of the windpipe. It attains its maximum development in the whistling swan, where the tunnel expands to invade the bony tissue of the hinder end of the body of the sternum itself. Here we have two entirely different organs reacting in a reciprocal manner. Surely no better, or more convincing illustration can be found in support of my contentions as to the effects of persistent stimuli in molding

the growth of organs. There are some other birds, I would remark, wherein also we find a hypertrophied growth of the windpipe. But the course taken has been very different. In the painted snipe (*Rhynchea*) and the purple manucode (*Phonygama*)—one of the birds of paradise—the windpipe has come to form long coils or loops between the breast muscles and the skin, while in the spoonbill it forms a figure-8 loop immediately under the lungs. But here, meeting with no resistance, no secondary modification of any other organ was needed.

Let me cite yet one more case—and I could find a hundred. This is furnished by the hoatzin. It feeds largely on the fruit and leaves of the thorn-tree (*Drepanocarpus lunatus*) and of a species of *Echites*. One or other of these has probably some astringent properties, that brought about a thickening of the walls of the crop, which gradually assumed the form and functions of the gizzard, now reduced in size and superseded. As a consequence, the pressure of this gizzard-crop against the anterior border of the keel of the sternum gradually forced it back, a process accelerated by the fact that the breast muscles had already become reduced from lack of use, as in our waterhen. The crop developed, in short, at the expense of the keel. As a result all that is now left of the keel is a small, triangular projection at the extreme hinder end of the sternum. Furthermore, this pressure of the crop has forced the furcula upward, so that it has come to lie between, and parallel with, the coracoids, while its conjoined extremities have fused with the sternal plate.

Here, surely, we have unmistakable evidence of the effects of persistent stimuli, such as mold every organ of the body according to the intensities and nature of its use.

It seems impossible to attribute these instances of "reciprocity" in development to "natural selection", nor can they be set down to the action of the "environment." In the case of the windpipes we have two totally different organs involved, one belonging to the respiratory, the other to the skeletal systems, producing, as I have shown, reciprocal changes. But whether this excessive lengthening of the windpipe is due, in the first place, to hypertrophy, or whether it has been brought about by some unsuspected and undiscovered strain in the production of the voice, is a matter for further investigation. In the hoatzin, then, we have a very singular relationship set up between the alimentary canal on the one hand, and the skeleton on the other. They are precious sign posts in our search for the causes governing the transformations of living bodies.

No less important are cases—and they are legion—of "degradation" or "retrogression", sometimes strangely associated with the

evolution of new characters. Living things, it is indeed true, have "les défauts de leurs qualités."

While we may look for, and find, similar results arising from like stimuli they will always present contrasts because, as was pointed out earlier in this address, no two organs, even of the same species, are ever exactly alike in the composition of the substances which form their tissues. And these differences become more marked as we pass from individuals to species, and from species to genera, and so on, in ever widening circles. But such organs show a striking convergence as their functions tend to be changed by the rhythm of the stimuli following changes in habit, or habitat, in the individual, in the pursuit of its food, perhaps the most common inciting cause to change. And thus it has come about that by this "convergent evolution" animals not even remotely related have come to assume a conspicuous likeness in their outward appearance. The Cetacea and the extinct Ichthyosauria afford a striking illustration of this.

But first let me say something of the Cetacean flipper. This, when the whole group comes to be surveyed, presents some very remarkable differences of which there is no indication until dissection is resorted to.

It will suffice for my purpose now, to bring to your notice some of the more striking of these differences, though in all these cases the changes in the skeleton, as compared with land dwellers, are profound. No indication of the normal segments of the limb or of digits are visible externally. Dissection shows that in the ziphoids and in Platanista the structural change in the skeleton is less marked than in any other cetacean, since the carpal region presents no more than the early stages of decadence.

In the rorquals we find the same elongated form of the flipper as in the ziphoids, but here we have what must be interpreted as a very striking and interesting case of "arrested development", for the wrist bones fail to attain to complete ossification; either no more than a nodule of bone is found within the several cartilaginous forerunners of the carpal bone, or these remain permanently cartilaginous, even, in some cases, fusing one with another. Moreover, these bones have become reduced in number in all the Cetacea. In the killer whale (*Orcinus*), and in the humpback (*Megaptera*), the vagaries of development attain their maximum (pl. 4). In the first named the ossification of phalangeals, or "finger joints", has become reduced to narrow bands, which, in the terminal series of the second digit, are represented only by their preaxial moieties. These ossified portions are separated by enormous masses of cartilage, while the second and third digits are curved round as though they had grown within a

shell too short to allow them to extend. It is a most puzzling and extraordinary flipper, which so far cannot be precisely correlated with its "use." No less remarkable is the flipper of the humpback (*Megaptera*). This is of enormous length; in a female 49½ feet long it measured 16 feet. As with the typical rorquals the number of the phalanges in the second and third digits have greatly exceeded the normal three of the mammalia generally. They are relatively long and slender, and shaped like a dice box. But here, as in the killer, the ossified portions of the phalangeals are capped at each end by an enormous mass of cartilage, and these, along the front, or pre-axial border of the flipper, produce in the living animal the series of notches found in no other whale. The largest of these is formed by the cartilaginous mass at the end of the first digit which terminates with strange abruptness.

Very few of the Cetacea have retained all five digits. We find this number in Platanista, and in the right whales. Naturally it is assumed that it is the pollex, or first digit, which is missing. But the flipper of the common rorqual (*Balænoptera physalus*) urges caution in this connection. For with some constancy the terminal end of a digit is found between the second and third of the existing digits, suggesting that reduction has taken place by the suppression, or "squeezing out" of the third digit, and not by the loss of the pollex. In all the Cetacea the fingers lie embedded, as in a solid, fingerless glove, either extended parallel with one another or radiating. But in the right whale the three first fingers lie parallel, and close together, while the third and fourth stand wide apart, as seen at the right of plate 4.

Some still hold that all the varied types of animals we know, fossil and recent, have come into being through the agency of natural selection. But surely "natural selection" has not determined the absence of cartilage, save for articular surfaces, in some flippers, and its enormous development in others. We cannot invoke this agency to explain the remarkable flippers of the killer whale and the humpback. Again, what survival value can the notches on the flipper of the last-named species have had? If the humpback has survived in the struggle for existence because of the peculiarities of the internal skeleton of this limb, why have the ziphoids, living the same mode of life, and in the same medium, survived with a totally different flipper?

Make no mistake. The strange and apparently meaningless differences in these several forms of flippers are the expression of the effects of precisely similar stimuli on tissues of different inherent qualities. Each has responded after its own fashion.

Confirmation of this contention is surely to be found in the flipper of the Ichthyosauri—reptiles, be it remembered—which lived millions of years before the Cetacea came into being. Like the Cetacea, and

the Sirenia (manatees), they were entirely aquatic, and in like manner, in consequence, assumed the same general form in regard to the body as a whole, and the flipper in particular. But when we come to examine the skeleton of this limb we find more surprising differences. Here cartilage, in the adult stage, had no place. Moreover the fore-arm is found to have become so shortened as to require expert examination to distinguish its component elements—radius and ulna—from the carpal, or wristbones, and these, in turn, often by no means easy to distinguish from the phalanges, are crowded together to form a close mosaic. In the "finner whale", it may be remembered, one digit had apparently been "squeezed out" so that only its terminal portion remained. We find the same "squeezing" in regard to one of the digits—the second—in some species of Ichthyosaur's paddles. But here, only the extreme proximal end is wanting. A further peculiarity is found in a row, or sometimes two rows, of ossicles along the post-axial border of the hand. These were nodules of bone formed in an external "fin-membrane", apparently, as one might say "to give increased width", though this phrase must not be taken to imply "a means to attain an end." We shall be nearer the truth in assuming some peculiarity in the mode of swimming, bringing into play a marked stimulus to the skin along this border of the flipper. This may well have been the case, for the tail of the Ichthyosauri was directed downward, and carried vertical "flukes."

Here, then, in all these cases, we have evolution and decadence going on at the same time, a fact well worth bearing in mind, for it has not yet received the attention it deserves.

And now let me pass to consider the theme of "arrested development", to which I have already referred. Its more important aspects can be briefly reviewed. We can find no clearer, or more convincing examples of this aspect of evolution than are furnished by the Cetacea, and, in the first place, by the flippers of the rorquals, including the Humpback. For in these the ossification of the phalanges is never completed, each end being capped by masses of cartilage. In the embryonic development of the manus of all the land animals there is a stage which exactly corresponds to this permanent, adult condition, found in all but the most primitive cetaceans. More striking still is the vertebral column. In all the higher vertebrates the lumbar vertebrae are free, and succeeded by a series of fused bones which have become specially modified by having become immobile owing to the grip of the pelvic bones. They are known as the "sacral vertebrae." In the Cetacea there is no sign of sacrals. The vertebrae pass insensibly from the lumbar to the caudal series. But there is a precisely similar absence of "sacrals" in the developing vertebral column of all the higher vertebrates. For the sake of contrast I cite the condition

found in the developing human embryo. At one stage the pelvic bones are embedded in the body wall some distance below the vertebral column. But in time the iliac elements enlarge, until they reach, and finally embrace, the vertebrae to give rise, finally, to a "sacrum."

The vertebral column, then, of the Cetacea, must surely be accepted as another instance of "arrested development", and we may take it that it has come about by the gradual decline in viability of the pelvic bones which, as I shall presently show, have become reduced to mere vestiges. In other words the sacral vertebrae do not form "in anticipation" of the contact of the pelvic bones. If the stimulus of the contact of the hip girdle is not given they remain in their "embryonic" state.

We may fittingly pass now, from "arrested development" to the subject of "vestiges"; for the one is the forerunner of the other. When any organ tends to be relieved of its functions it begins to decrease in size. But the process, as I shall show, is infinitely slow. Tens of thousands of years must pass before the period of decline ends somewhere near extinction. In some cases it may be that the time of the passage is less, but we have no evidence of this, nor can we hope to find any. Hence one cannot but express surprise at the suggestion that has been made more than once, that "nature removes useless organs for the sake of economy." No man could measure the "saving of tissue" effected in a single generation, or a dozen generations. Where, then, can be the benefit of such "economy" taking a million years to achieve?

The stages by which an organ passes from functional activity to the condition of a vestige are illustrated in a very striking manner, in the case of those lizards known as "skinks." Since the nearly related family Anguidae contains both limbed and limbless forms, and dates from the Lower Eocene, we may take it that the Scincidae are not less ancient. In these skinks one can follow, in four different species of the genus *Chalcides*, and one of the genus *Lygosoma*, a singularly perfect series in the reduction of both fore and hind legs, showing first a general reduction in size, and then a reduction in the number of the digits from five to two, till finally all that is left is a small, scaly tubercle. Since we know the geological period when the Anguidae started on a precisely similar course we may assume that this process of reduction in the Scincidae began at the same time, some millions of years ago!

When we turn to the Sirenia, among the mammals, which also date back to the Eocene, we find the fore limbs in the form of flippers like those of a cetacean, and no external trace whatever of the hind limb. But there is a striking series of gradually decreasing vestiges of the pelvic girdle, embedded in the abdominal wall. And here we have a more complete time-scale. The series begins with

Eotherium of the Middle Eocene, some 20,000,000 years ago. Here we have a complete innominate bone, but reduced in size. In *Eosiren*. of the Upper Eocene, the obturator foramen had disappeared, and the acetabulum greatly reduced: *Halitherium*, of the Middle Oligocene, shows a still further reduction of the pubic and ischial elements. In *Metaxitherium*, of the Middle Eocene, the pelvis is reduced to a mere protuberance, and the acetabulum is closing up. Finally, in the dugong (*Halicore*) and manatee (*Manatus*) of today, nothing is left of the pubis, and but the merest trace of the acetabulum, while the innominate, as a whole, has become a mere rod, as shown on plate 5.

These changes, be it noted, were accompanied by other changes external and internal, sufficiently great to divide the members of this continuous series into distinct genera, whether we allot 15,000,000 or 20,000,000 years to this chain of evolution does not greatly matter; we have geological evidence that the process was infinitely slow. How, then, can we hope to "prove" or refute, the "transmission of acquired characters" by experiments carried on with white mice, for a dozen generations or so.

Let us turn now to a precisely similar story in regard to the hip girdle of the Cetacea, though here we are confined to the evidence afforded only by species still living. But it brings to light another aspect, the significance of which seems to have been overlooked, and this concerns the fact that these retrogressive changes vary somewhat conspicuously in different individuals. The reduction is least in the Greenland whale. But even here the pubis is barely distinguishable, and the acetabulum a mere depression. The pelvic limb is represented by the femur, and a portion of the proximal end of the tibia reduced to a mere nodule of cartilage. Both in size and shape the femur presents wide differences, ranging from a rod-shape, to a quadrangular plate of bone, and the tibial cartilage is no less variable. And the same is true of the fin whale (*Balaenoptera physalus*). The innominate is little more than a mere rod, but with a bifurcated posterior extremity representing the last traces of ischium and pubis. There may be a roughly rod-shaped femur, with a nodule of cartilage answering to the proximal end of the tibia, or there may be no more than a small nodule of bone representing the femur. The acetabulum has vanished. In the Odontoceti the process of degeneration has proceeded still farther. Only in the sperm whale *Physeter* is there ever as much as a nodule of cartilage answering to the femur. That the increments due to use are more rapid than the processes of absorption is a matter which cannot be determined.

My friend Prof. O. Abel in his fine book on "Palaeobiologie", has brought together a remarkable collection of facts in regard to changes

in the form of the vertebrate skeleton in relation to modes of life, and his inferences thereon are worthy of more serious attention than they have yet received. On this theme of the gradual reduction of the hind limb in the Sirenia, and the Cetacea, he draws attention to the fact that this reduction is to be attributed to the fact that in both groups the body is propelled through the water by horizonal, laterally expanded, tail flukes; while in the Ichthyosauria, wherein the tail was down-turned, and had vertical flukes, the hind limbs are present, though reduced in size. This is really a very important observation. Neither "natural selection" nor "environment" nor "genes" can have had part in these changes, which are due to the mechanical effects of continuous and intensive stimuli on the parts affected, with a corresponding reaction on the adjacent associated structures.

The wings of birds furnish, perhaps, the most complete history among the vertebrates of the course of the slowing down of the activities of an organ until it ends in complete disappearance. For it is a matter of common knowledge that birds of feeble powers of flight have rounded wings. And there are some species, as for example the wryneck, where the process of shortening sets in after the first juvenile molt. For here the outermost primary is nearly three times as long as it will be in any succeeding molts. Birds on islands tend to become flightless where there is no incentive to flight. The wing is yet complete, but often too small for flight. In the struthious birds we find almost every stage of decadence, from the relatively large wing of rhea—but useless for flight—to the diminutive wings of the apteryx, cassowary, and emu. In the extinct Hesperornis only the upper end of the humerus remained, and in the Dinornithidae the process of reduction proceeded till finally every trace of a wing is lost; even the socket for its articulation has disappeared from the shoulder girdle, itself degenerate in every other aspect. And always, as the wing declines so also does the keel of the breastbone, leaving, in Hesperornis, and the struthious birds, no trace whatever, save in the case of the embryo of apteryx.

This history of vestiges rules out of court, in the most emphatic way, the contentions that have been made to explain them as the outcome of "natural selection", or of the need for "economy", nor can they be attributed to the effect of the environment. They have followed a perfectly natural, and orderly sequence, resulting from a continuous sequence of disuse. There are hundreds of cases of vestiges, furnished by all kinds of organs, and always and everywhere, they have attained to this condition by the same inevitable process.

And now let us turn to an exactly opposite trend of evolution, seen in cases of what we call "hypertrophy." Herein organs increase

in size to an abnormal extent, though without materially changing their form. In some cases, indeed, so as to endanger the well-being of the victims of such excesses. A striking example of this kind is found in the tusks of the mammoth, which, growing forward at first, then curved backward and outward on themselves, attaining to a length of as much as 12½ feet.

Now the mammoth had come to live in treeless tundras, hence, since there were no trees to bring down for the sake of their fruits, by levering them up by their roots with the aid of the tusks, there was no check on the growth of the tusks. In other organs disuse is followed by a reduction in size, ending in a vestigial state, and final disappearance. But the great weight of the tooth in the socket set up vibrations in walking which were sufficient to stimulate the continuously growing base, while there was no directing force controlling growth. Hence, these teeth not only far exceeded their normal size, but by their form were useless even as weapons. In the saber-tooth tiger, again, we find the canines excessively enlarged. So much so that the strain of the muscles and their increasing size brought about a peculiar construction of the glenoid surface of the jaw-hinge, to permit the mouth to be opened sufficiently to feed. The socket of this canine extended upward far beyond that of normal carnivores, as a consequence of the extra strains set up in the tooth. But more remarkable still is the case of the recently described "saber-toothed" marsupial *Thylacosmilus*, which, by the way, furnishes yet another and most impressive example of the effects of "use" as a molding force. For this animal was not even remotely related to the true carnivores. Here, however, the matter at issue is the enormous canine, the root of which extended upward and backward over the roof of the skull, a condition known in no other mammal. What gave rise to so extreme a case of hypertrophy there is no evidence to show. But more than this: The inferior border of the mandible, immediately below the canine, developed a great flat plate of bone, wider than the tooth, and projecting downward beyond its point. A similar but smaller projection is found in the true Miocene and later saber-tooths, and it is found again, of great size, in the huge Eocene ungulate *Tinoceras*. Was this brought into being as a result of persistent contact of the lower border of the mandible with the projecting tooth? Layard's beaked-whale (*Mesoplodon*) is still more remarkable. For herein the lower jaw bears only a single pair of strap-shaped teeth and these gradually grow upward to meet finally above the snout; apparently making it impossible to open the jaws beyond a mere slit. The teeth of the ziphoid whales present many remarkable and puzzling features, which, however, in this address cannot find a place.

Here, as in the case of the hypertrophied antlers of the extinct Irish deer, this excessive development, beyond functional requirements,

imperils the safety of the species, by undermining its vitality, hampering it in endeavoring to escape from enemies, and in obtaining food.

Closely associated with, and perhaps hardly separable from hypertrophy, is the development of excessive "ornament", whether it be the plumage of birds of paradise, or peacock's, or in the "excrescences" of bony structures in the forms of horns, or outgrowths on the body, found in the case of so many extinct types of animals. Sir Arthur Woodward, one of the foremost paleontologists of our time, has drawn special attention to phenomena of this nature, which he interprets as the final "flare-up" of the lamp of life before extinction. Having attained to their maximum size and weight, all further surplus material for growth was expended on "ornamentation." And this is a view which will probably find general acceptance.

Let me pass now to two closely related aspects of animal life which afford convincing evidence, in support of my contention, that living bodies, whether of animals or plants, are self-regulating in the matter of the growth, both of their external and internal organs. These aspects are furnished through what are known as phylogeny and ontogeny.

The history of the evolution of the elephant forms a pageant which held the stage for some 30,000,000 years. As an illustration of "phylogeny" it is well nigh complete. But I can do no more, here, than select a few of its more interesting phases, showing its trend. The complete story has been told by the late Prof. Henry Fairfield Osborn, the greatest authority of his time on this theme. He distinguished four main lines of descent, and 300 species, displaying a most marvelous series of gradations in the evolution of the tusks, and the great molar teeth, a progressive series, accompanied by an equally progressive increase in size.

Reduced to its simplest terms, and most essential features, then, it begins with Moeritherium, a semiaquatic animal discovered some years ago by my old friend and colleague, the late Dr. C. W. Andrews, in the Eocene deposits of the Fayum. In general appearance it may be likened to the pigmy hippopotamus. Attention is more especially to be directed towards its teeth, of which there were 36 in all. The upper jaw, on each side, bore three incisors, one canine, three premolars, and three molars. The lower jaw had but two incisors and no canine. The outer pair of the upper incisors, it is to be noticed, were large and directed downward, while the outer lower incisors, large and chisel-shaped, were directed forward and slightly upward. The gap between the cheek teeth and the incisors of the lower jaw was but slight, and this is a fact to be borne in mind, in view of what follows.

Dr. Andrews regarded Moeritherium as the direct ancestor of all the elephants. But Professor Osborn dissented, holding it to be off the direct line of descent. Be this as it may, the animal he designates as the ancestor is not so very different in essentials. This was *Phiomia*, of which there were four species of increasing size. Their incisors closely resembled those of *Moeritherium*, but those of the lower jaw were gradually borne forward by the extension of the jaw, so as to keep the teeth in touch with the ground, the lengthening of the neck being inhibited by the intensive use of the jaw as a digging instrument. *Palemastodon* marks an important stage in this development. Herein the upper tusks are beginning to turn forward. We have passed now from the Mid-Eocene to the Lower Oligocene, a period representing several million years. This process of the lengthening of the lower jaw, bearing the digging teeth, culminated in *Trilophodon* wherein it attained a length of 6 feet 7 inches, the teeth being borne at the end of a long beam!

To keep pace with the lengthening jaw, the upper lip became more and more elongated, passing from a tapirlike snout into a gradually lengthening proboscis. With such a very mobile, and efficient grasping organ, which enabled browsing to replace digging, the reduction in the length of the lower jaw started, and the typical elephants, fossil and recent, came into being.

But this is not the whole story. There were many divergent branches. In some the lower jaw expanded at its tip, giving rise to the "shovel-toothed" mastodons, in others as in *Deinotheres*, the lower incisors, borne on a relatively short jaw, turned downward, to form a pair of great hooks.

During all this time the cheek teeth, or "grinders", were becoming reduced in number, but larger and larger and more and more complex, well seen in the African and Indian elephants of today. When one comes to realize that this pedigree of the elephants covers a period of some 30,000,000 years, it becomes apparent that the effects of use and disuse are ponderously slow. But they are nevertheless very real.

Here we have striking sequences of growth regulated by the strenuous use of the jaw in digging which inhibited the lengthening of the neck. Later, this inhibition was enforced by the increasing weight of the head, due to the progressive enlargement of the tusks and trunk and their consequent weight.

As an example of the effects of intensive use in the history of the evolution of a race, this of the elephant, and the horse, is the most complete.

And now let me pass to a brief summary of "ontogeny"—the gradual development of the body of the individual from the em-

bryonic to the adult state. As with phylogeny—the history of the race—a whole series of addresses would be necessary to exploit this theme adequately. Hence, I must be content with but two illustrations confined to postembryonic development, by way of illuminating, if possible, the trend of my contentions in this address.

According to the recapitulation theory, with which I have no quarrel, every animal climbs its own ancestral tree. That is to say, it repeats in the course of its development, from the embryonic to the adult stage, the successive stages which marked the development of its ancestors, near and remote. Many objections have been raised to this conception, but these were largely based on a too narrow interpretation of its terms.

In its essential features there can be no escape from "recapitulation." For though all living organisms, plant or animal, are composed of the same basic substances, so far as we can analyze them, in no two are the qualities of that substance alike; as I showed, in the beginning of this address, in the cases of the mold Penicillium; and the qualities of the tissues of the ox and the sheep, or the grouse and the pheasant. Hence, they will respond differently to similar stimuli. The effects of such stimuli are found in changes of form in adjustment to "use." Whether the organism be a single cell, or a vast complex of cells, it will retain and intensify its responses to such stimuli after its own peculiar fashion, so long as its race exists. That is to say its responses or "acquirements" are transmitted from one generation to another. This conclusion is inevitable. But it is by no means in accordance with current views inspired by Weissmann's germ-plasm theory.

According to this there are two kinds of "plasm"—the "germ-plasm" and the "somato-plasm." This last forms the visible, tangible body which is derived from the germ-plasm leading a cloistered life within the body it has given rise to, but not of it. It is held, then, that it is the germ-plasm which forms the body; and any differences observable between any two closely related bodies, whether of the same species or more distantly related, are due entirely to changes which have come about in that germ-plasm, which is supposed to be unstable, and thus constantly giving rise to the variations we find expressed in the somato-plasm. The germ-plasm is the golden calf of biology, and woe betide those who fail to render it homage.

Let me take two concrete cases of "recapitulation." Twenty would serve me better. They are shown on plate 6.

The first is that of the postembryonic stages of the angler fish, chosen because of its striking contrasts. In the earliest stage it will be noted the body tapers backward to a point. Of the fins there is but a small pectoral, a rudimentary first dorsal fin ray and pelvic

fin. In the second there are two conspicuous rays to the dorsal fin, and the pelvic fin has taken the form of two rodlike rays of unequal length. The pectoral has greatly increased. The third stage shows four dorsal fin rays, two subequal and greatly enlarged oarlike ventral rays, and still a tapering tail. Further, it should be noted that a fin membrane, unsupported by rays, runs continuously along the body from the dorsal fin backward and forward to the vent, as in the earlier stages. In the fourth stage the dorsal fin rays number five, but much increased in size and changed in shape. The pelvic fin rays have materially changed in shape and proportions, the lowermost extending backward as a long filament far beyond the body. The tail no longer tapers backward. Its extremity has turned upward. Herein is indubitably an ancestral character, recalling the tail of the shark tribe, which have a more ancient ancestry. Above the upturned portion is a relic of the earlier continuous fin membrane, and below it are a series of fin rays that will remain to form an apparently "hormocercal" tail after the upturned portion has been absorbed. This transformation from the upturned, or "heterocercal" sharklike tail fin is found in nearly all the higher fishes during larval life. It is a "recapitulation" of an ancestral character. It repeats this stage because it is still following the "route" along which the hormocercal tail traveled in the course of its evolution. There are some cases where a short cut has been taken by missing out the upturned phase. Finally, note that out of that continuous fin membrane two new fins have appeared, a second dorsal and an anal fin, and there are still traces of the earlier, rayless fin, at the base of each.

Now compare these with the strikingly different adult stage, which is characterized by its enormous head and mouth, strangely depressed, so that the head is no longer round, but flat. The eyes are no longer on each side of the head, but look upward, side by side. The pectoral fins now project at right angles from the body, and lie flat, with the head, on the sea floor. The body has, in short, been transformed from that of a free-swimming fish to a sedentary. Instead of hunting for food in midwater as in its infantile stage, it now lies flat on the bed of the sea. And other and very remarkable changes have followed this changed mode of life. Briefly, the rays of the dorsal fin have become widely spaced. The first dorsal has shifted forward to the snout and developed at its free end a flaglike fold of skin. At the same time the enormously enlarged mouth and the sides of the head have developed similar "tags of skin" forming a fringe. These can be set in vibration and look like pieces of seaweed, moved by the currents. The "flag" on the snout is used as a lure, being gently waved when small fish are in the neighborhood. Presently they draw near to investigate, when

they are engulfed by the inrush of water into the mouth caused by the sudden opening of the jaws.

Now let us take the case of the larval swordfish (*Istiophorus*). In the first stage, it will be noticed the jaws are relatively short, of equal length, and armed with teeth. There is a long, and very low dorsal fin, and a relatively large pectoral fin, and a conspicuously large eye. From the gill-cover project two long spines, one just behind the upper segment of the eye, the other and much longer, on a level with the base of the lower jaw. In the second stage the upper jaw has slightly increased in length. The dorsal fin is much larger, the upper opercular spine is relatively smaller, the lower has become more slender, and relatively shorter, while a pair of long filamentous pelvic fins have put in an appearance. The third stage shows approximately the adult stage. The upper jaw has become much longer than the lower, and has assumed its swordlike form, the dorsal fin has risen to a great height; the upper opercular spine has disappeared, and the lower is greatly reduced, while the teeth have vanished. The eye and the pelvic fins have also decreased in size. There is no reason to believe that the opercular spines and the pelvic fins are "ancestral characters", but rather that they are adjustments to larval life. But the temporary armature of teeth is probably recapitulatory since they are reduced to a vestigial condition in the adult.

Animal bodies being, as I contend, "self-regulating", they naturally, and of necessity, move along the old track as they gradually approach the final form attained by the race by adjustments to conditions imposed by changing and changed modes of feeding, for that is what these changes commonly mean in the long run.

It does not follow that the particular changes in the form of the fins of the angler fish must also be regarded as ancestral adult characters. By no means; they are adjustments which have been made by successive larval ancestral stages in adjustment to the particular stimuli set up in these rays by the efforts made to retain their position in midwater and their source of food, just as much as the woodpecker's tongue, or the three-toed foot, are adjustments to intensive stimuli. Organs, or parts of organs, as I have already urged, change their form, and increase their size—and therefore their efficiency—by use. The first woodpecker probably caught ants as easily as the last of his race. But just as the continuous and peculiar movements of the tongue made by the first ant catchers gave rise to the long, protrusible tongue, so the stimuli given by the formic acid exuded from the bodies of the ants, gradually increased the size of the salivary glands. These larval fishes have changed after the same fashion. Their long fin-rays become reduced as their use declines,

by the gradual passage into the newer, and final stage of life. Young Crustacea, and young Mollusca, show precisely similar, and indeed, often more striking changes in their "ontogeny." There is no need to regard them as adult ancestral characters.

There is no need to postulate irresponsible vagaries of the "germ-plasm" to be weeded out by "natural selection", or sorted out and increased or rejected by "genes" hidden away in the chromosomes, and defying detection even by the highest powers of the microscope, in attempting to account for the phases presented in ontogeny.

As the orderly sequence of development proceeds, the germ cells are in due course formed out of the nascent tissues, just as are the ancillary structures necessary to their survival—the generative glands and ducts, and all the other organs and tissues of the body.

There seems to be no warrant for a belief in a special "germ-plasm" potentially variable, and ultimately expressing that variability in the "somato-plasm", which, whatever changes it may undergo in response to external influences, is unable to transmit such changes, being capable only of producing the visible, animated body.

But if the term "germ-plasm" be accepted merely to distinguish the germ cells—ova and spermatozoa—which, as they develop, after union, gradually build up again a body after the fashion of its race, many of our difficulties in studying problems of descent will vanish. We do not, except in a very general sense, postulate a "germ-plasm" in the case of the Protozoa. If we say Amoeba is composed solely of "germ-plasm", or of "somato-plasm", we are merely making a distinction without a difference. But if the substance which forms the body of the Protozoan can reproduce other like bodies indefinitely, we need ask no more. For the Protozoa display an infinite variety of forms, free-swimming and sedentary, ciliated and flagellated, naked, and with a hard-skeleton, and showing adjustments to astonishingly varied conditions, including parasitism. The Metazoa do no more.

The passage from the Protozoa to the Metazoa is by no means an abrupt one. When, and where, did the distillation and isolation of Weissman's "germ-plasm" take place? When does it expel from itself the substance called the "somato-plasm" charged with building up a new body? And in what part of that developing body, beginning with the first cleavage-plane, does it establish itself, in the Metazoa, until all is ready for it to take up its final resting place and to begin the formation of new "germ-plasm"?

Only some of the more specialized Protozoa form out of the substance of their bodies definite male and female germ cells, and on these the final continuation of the race has come to depend, as in

the Metazoa. But between the formation of relatively complex bodies such as we find in the vorticellids, or in Volvox, and the still more complex bodies of the Metazoa ending with the vertebrates, there are only differences of degree, not of kind.

A leaf cut from a begonia plant and laid flat on damp earth will produce new plants, which, in the course of time, will put forth flowers and seed; whence comes the "germ-plasm" of these seeds? Who can doubt that it was distilled from the normal process of metabolism, and is endowed with the power of reproducing new plants. These, in due course, give rise to flowers, and seeds, differing in no wise from plants derived from a "zygote." The protoplasm of this begonia leaf, in short, possessed all the qualities of its race, and in due course built up a new plant exactly like that from which it was derived. It could do no other. For though by no known process of analysis could we distinguish between the "germ-plasm" of a begonia and that of a bean, yet each has its own peculiar qualities and endowments, and inevitably they reproduce after the manner of their kind. But they are not immutable. Like all other living bodies, the tissues of which they are made up are all responsive to intensive stimuli, so that they of necessity are subjected to a higher rate of waste through such stimuli, and in consequence will absorb more of the "food material" manufactured to sustain life. Hence such parts come, in succeeding generations, to change their shape, and at the expense of some other tissues, which may become reduced to a vestigial condition. As a result new "varieties" and new "species" and genera and so on arise.

Throughout the whole vegetable and animal kingdoms these subtle agencies are at work, resulting, as I have said, in "self-regulating" bodies.

In short, that same "somato-plasm" which builds up the complex human body, bone and muscle and nerve, the oviducts, the uterus, the testes, and sperm ducts, can, and does also build up the ova and the spermatozoa. What we call "heredity" is but the expression of one of the orderly sequences of growth, inherent in the substance which has worked out its own salvation in the course of the ages. That this substance differs in its qualities, in every living thing, is manifested in the infinite variety which living bodies, whether of plants or animals, present.

The Mendelians account for the results obtained, for example, by crossing tall and dwarf races of peas or fowls with different forms of combs, by attributing these several characters to the agency of "entities", which they designate "genes", or "factors." These, it is held, can be transmitted respectively by the sperm and the ova, which form, at fusion, the "zygote." Tall and dwarf individuals of this hybrid parentage reappear in the second generation. In some cases

combinations of these genes give rise to new forms—rose, pea, and walnut-combs. By suitable mating, in further generations such genes, or "factors", can be "sorted out", and the original form regained. But the competence of this interpretation rests on the assumption, in the first place, that the germ-plasm is a substance apart from the somato-plasm, to which it gives rise, and in the second that these qualities of "tallness and dwarfness", for example are, in effect, separate entities in the germ-plasm. On this assumption, of course, all characters, whether of structure or coloration, are as much entities as is the whole organism. This conception, however, presents insuperable difficulties.

The work which has been done, based on the original experiments of the Abbé Mendel, is fascinating, and has produced some remarkable results. But, greatly daring, I venture to suggest that they would be as easily explained as due to the mingling of slightly different strains of somato-plasm.

More than this I cannot say here, since this address must not exceed the normal bounds commonly prescribed for addresses.

Use and disuse, surely, are the primary forces in the history of evolution. Lesser parts are doubtless played by "natural selection" and "environment", under one or other of an infinite number of forms.

So long as we insist on regarding biology as a crystallized creed, requiring no more than a possible rectification of some of its tenets, so long shall we continue groping in the dark to get an insight into the mysteries we are professedly trying to solve. But I venture to hope that some, at least, who will read this address, will do so without bias, in the hope that, perhaps, they may really find a new angle from which to survey their beliefs. Hostile criticism, like abuse, is no argument. A review of our position today, as biologists, is undoubtedly called for. I feel that I shall not have written in vain if I induce at least some to endeavor to make that review.
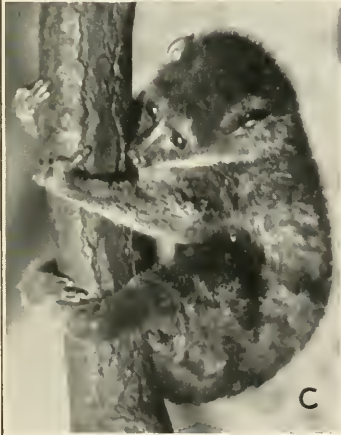
PROGRESSIVE STAGES IN THE MOLDING OF THE LIMBS, IN RESPONSE TO INTENSIVE
CLIMBING HABITS.

A, Grey cuscus (*Trichosurus maculatus*); *B*, koala (*Phascolarctos cinereus*); *C*, awantibo (*Arctocebus
calabarensis*); *D*, three-toed sloth (*Bradypus tridactylus*).

PLATE 2
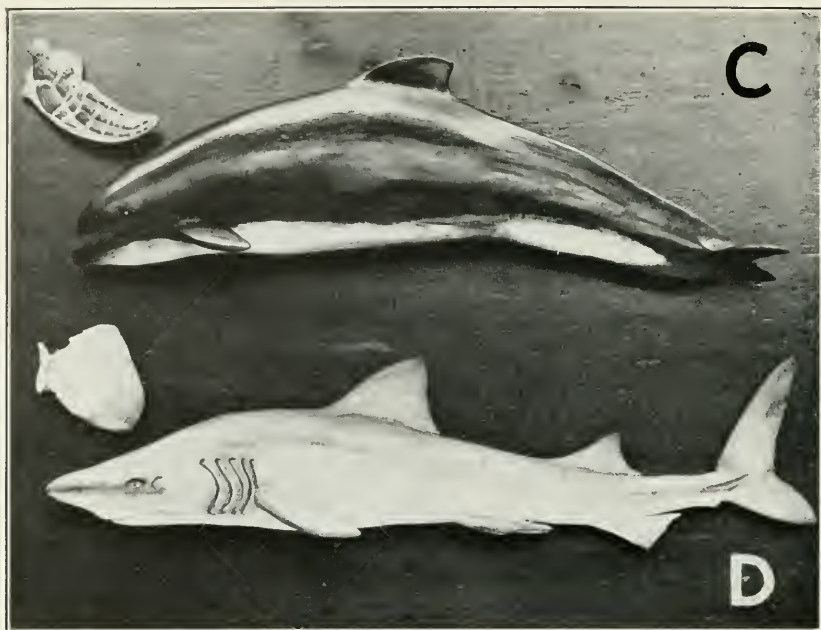
CONVERGENT EVOLUTION.

Here totally unrelated animals have come to assume a close general resemblance in accordance with their similar mode of life.   C, Porpoise; D, shark; H, sea lion.

PLATE 3
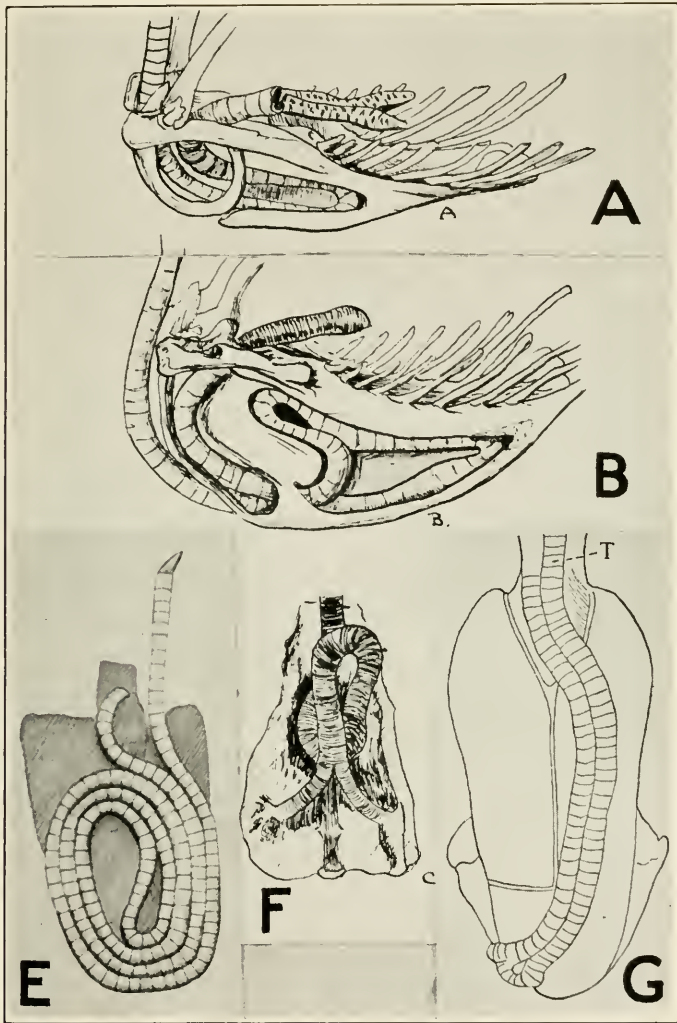
RECIPROCITY IN DEVELOPMENT.

The results of the persistent pressure of a gradually elongating windpipe against the anterior border of the keel of the sternum. *A*, Bewick's swan; *B*, a crane, and the course of a still greater elongation where little or no resistance is presented; *E, Phonygama; F*, spoonbill, *G, Manucodia.*

PLATE 4

CETACEAN FLIPPERS. EXTERNALLY CLOSELY ALIKE. (INTERNALLY THESE HAVE
VERY DIVERSE RESPONSES TO EXTERNAL STIMULI.)

A, Hump-back whale (*Megaptera*); B, bottle-nose dolphin (*Tursiops*); C, gangetic dolphin (*Planista*);
D, lesser rorqual (*Balaenoptera*); E, right whale (*Balaena*); F, pilot whale (*Globicephalus*); G, killer whale
(*Orcinus*).
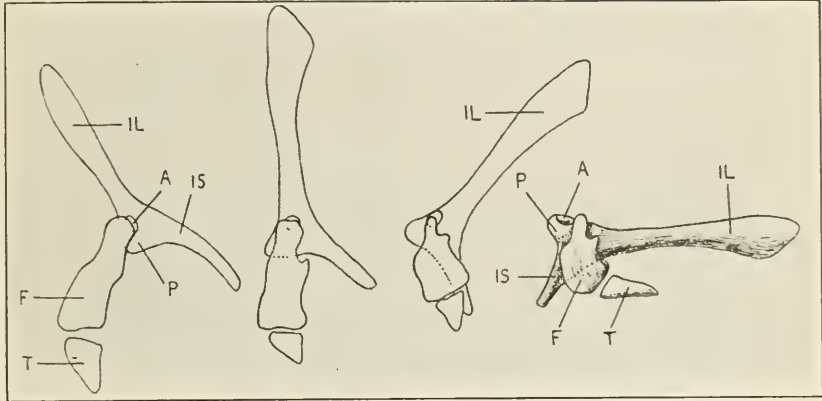
1. Stages in the degeneration of the pelvic limb from functional organs to vestiges, in different individuals, *Balaenoptera physalus.*
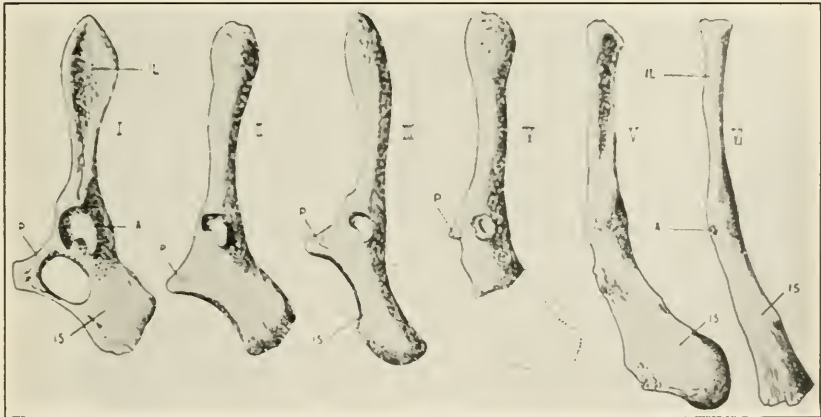
2. Stages in the degeneration of the pelvis in different generations of the Sirenia from Eocene times to the present day.

VANISHING ORGANS.

PLATE 6
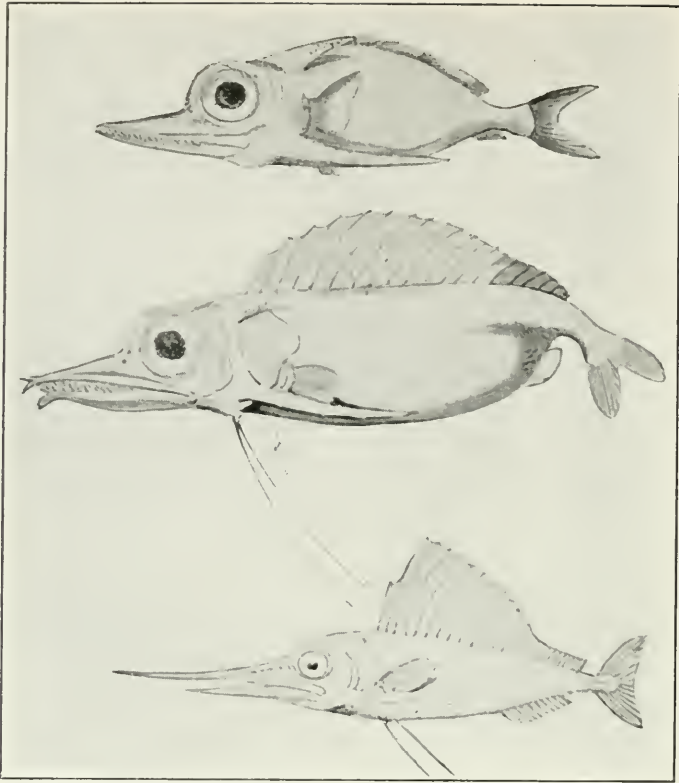
Stages in the development of the young swordfish.
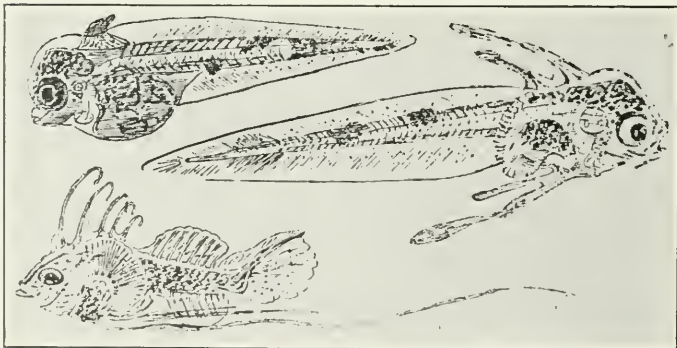
Stages in the development of the young angler fish.

NASCENT ORGANS.

WHAT IS THE MEANING OF PREDATION? [1]

By Paul L. Errington

The writings of antiquity contain references to the depredations of wolves, lions, and other predators upon flocks, and even to the attacks of predators upon man himself. But though the preying of one animal upon another has long attracted man's attention, man has made comparatively little effort really to understand such a conspicuous and universal phenomenon. The idea rarely occurs to anyone that there is a great deal to understand, the thought rather being that the predator kills and eats the prey, and that is all there is to it.

From this elementary concept of predation, a number of apparently logical conclusions usually are drawn. For example, if one predator kills so many animals of the kinds that are being preyed upon, more predators kill that many more; hence, more predators mean fewer prey animals. Conversely, if there were fewer predators, there would be more prey animals and so on. However, things do not always work out so simply in nature.

The widespread misconception of the effectiveness of predation in determining animal population levels is responsible for much reasoning that goes astray. Predation has been shown by recent studies not to be, in a collective sense, an inexorable tax upon the luckless prey species, to be satisfied in full.

Life to wild animals unquestionably is often harsh, but the demands of predators in temperate regions are not apt to be so drastic as to make existence a neck and neck race between the great appetite of predation and the breeding rates of the prey animals.

McAtee, for one, concludes that very few animal populations approach the limits of their food supply in nature,[2] and predator populations are not any general exception. Predators may occasionally starve, and predator pressure may at times be about all that a prey species can stand, or conceivably more than it can stand; but, for all

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[1] Journal Paper No. J374 of the Iowa Agricultural Experiment Station, Ames, Iowa. Project No. 330.

[2] McAtee, W. L., The Malthusian principle in nature. Scientific Monthly, vol. 42, pp. 444–456, 1936.

that, predation still seems to be essentially a byproduct of population rather than a broadly dominant influence on population. Failure to distinguish between cause and effect is a fertile source of confusion.

On the whole, predation seemingly depends more upon the opportunities predators may have to capture prey than upon any special advantage the animals loosely called predators may have over the prey from the mere reason of their being predators. It is true that some animals are highly specialized for a predaceous life and for no other, but even so they are only animals and their lives are circumscribed by natural limitations just as are the lives of animals which are not usually thought of as being predators.

Ecological studies indicate that, as concerns many wild species, there is only room in a given tract of environment for an approximately constant number of individuals, particularly of individuals that establish themselves in territories or regular home ranges and resist crowding past certain densities. The better grades of environment are filled up to capacity and any extra individuals either have to dispossess some that are already suitably located or must station themselves wherever they can. Those individuals that are well situated, of course, have the odds all in their favor compared with the less fortunate members of their kind that have to take environmental "leftovers."

Nicholson [3] has likened such territory-holding populations to water in an overflowing reservoir. It might be added that under circumstances of this sort, predation frequently seems to do little more than to lap up a part of the overflow and the leakage, and not always a major part of that.

Let us consider the popular bobwhite quail (*Colinus virginianus*), of which more is probably known of its life history and living requirements than is known of any other wild species. Stoddard [4] began his work on the bobwhite in the southeastern United States in 1924; Errington [5] and others have been working on it in the north-central States since 1929.

In Iowa and Wisconsin, researches on the food habits of various predators have been conducted along with the population studies of the bobwhite and other species, in one instance for 7 consecutive years on one area. The data resulting from these combined predator and population studies are not without their imperfections, but they are raw materials from which may be reconstructed a reasonably accurate and coherent picture of the functioning of some natural mechanisms.

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[3] Nicholson, A. J., The balance of animal populations. Journ. Animal Ecology, vol. 2, pp. 132–178, 1933.

[4] Stoddard, H. L., The bob-white quail. Scribners. 1931.

[5] Errington, P. L., and Hamerstrom, F. N., Jr., The northern bob-white's winter territory. Res. Bull. 201, Iowa Agr. Expt. Station. 1936.

Of the predator species resident in this region, the great horned owl (*Bubo virginianus*) has been investigated the most thoroughly and the most satisfactorily, both from the standpoints of its behavior and its food habits. From the quail observational areas alone, nearly 2,500 horned owl pellets have been collected and analyzed [6] and a large number of kills made by horned owls have been recorded in connection with field studies.

Correlation of the predation and population data from the above areas is simplified by the fact that, of the two species upon which an exceptional amount of research has been done, one proves to be the chief predatory enemy of the other.

The Cooper's hawk (*Accipiter cooperi*) and the goshawk (*Astur atricapillus*) may on occasion be truly formidable enemies of quail; but the horned owl has repeatedly demonstrated its ability to prey upon quail if any wild predator can, and it possibly kills more quail in the north-central States than all other wild predators together.[7] Quail remains have been found in as many as 10 of one lot of 30 horned owl pellets and in 19 of another lot of 85; and numerous other large lots have contained remains in from 5 to 15 percent of the pellets.

The reader may conclude, at this point, that the case against the horned owl as a quail enemy appears rather settled, and, as concerns quail conservation, looks distinctly bad for the owl.

Some may speculate further as to the role of the horned owl in the economy of nature and may contend that the direct damage inflicted upon the quail may be offset by indirect benefits resulting from the horned owl's activities as a whole—if not indirect benefits to the quail, perhaps to other wild creatures or to agriculture. But whatever may be the arguments advanced by those who may defend the horned owl, practically everyone appears to concede that heavy depredations upon the highly esteemed bobwhite represent a regrettable loss and, moreover, a loss preventable in large measure through reduction in numbers of the offending predator.

Now, suppose that it were to become public knowledge, in a community interested in the conservation of the bobwhite, that not only were horned owls abundant over the choice quail range but that each owl had been eating quail once a week, on the average, throughout most of the winter and would likely continue to do so for the rest of the winter and for weeks into the spring? In all probability, some action would be forthcoming, and it would be direct action of an easily predictable and understandable kind.

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[6] For a discussion of the reliability of pellet analysis as a method of study, see Errington, P. L., Technique of raptor food habits study. Condor, vol. 34, pp. 75–86, 1932.

[7] Predation by wild species should always be considered in a different category from predation by modern man; for discussions, see Errington and Hamerstrom, op. cit., footnote 5.

Such action might arise from an angry impulse to "punish" the owls for behaving in a manner perfectly normal to wild animals in the presence of an available food supply, or it might originate in an intelligent desire to give the quail needed protection before they were completely cleaned out. But, whatever else would be done, one almost certain result of any concerted action would be the killing of owls, and there would possibly be more or less talk about how many quail were saved thereby and some pencil-and-paper figuring as to how many more quail there would be next year.

Suppose, then, that some person said that, so far as quail conservation was concerned, the owls might as well have been left in peace; and that, for all of the owls killed, there probably would not be appreciably more quail surviving the winter than there would have been otherwise and that the figuring did not mean a thing? It may not sound like good old-fashioned horse sense, but such a person would stand an excellent chance of being right on all counts.

The evidence bearing upon this subject may be briefly reviewed.

The field studies of bobwhite populations had been carried on in Iowa and Wisconsin for 4 years, when it gradually became apparent that a given tract of land could winter an upper limit of only about so many birds under the most favorable of climatic conditions. The survival records obtained from local populations that had not suffered losses from shooting or from storm or starvation emergencies furnished the basis for the first accurate calculations of carrying capacity.[8] It was found that, while carrying capacity could be either raised or lowered, it commonly was remarkably definite for successive winters on a given area in established quail range, although not the same for all areas.

In the course of the field studies, it was seen that populations within the carrying capacity of their environment would usually survive the winter with slight loss except in the event of starvation or other emergencies brought on by deep snow, etc.; whereas, if the populations exceeded carrying capacity, the surplus birds would either have to leave or sooner or later be killed by natural enemies.[9]

Table 1 was prepared for the convenience of readers who may wish to see how the pressure exerted by horned owls on wintering bobwhites relates to bobwhite population densities and carrying capacities.

Quail remains were found in 119, or 7.9 percent, of the 1,504 winter horned owl pellets gathered from those areas where predation and bobwhite population studies were jointly carried on. Seldom would any single pellet be composed wholly of quail remains, and, even in

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[8] Errington, P. L., Vulnerability of bob-white populations to predation. Ecology, vol. 15, pp. 110–127, 1934.

[9] Errington and Hamerstrom, op. cit., footnote 5.

most cases where quail were represented, remains of some other prey would predominate. A quail victim as a rule would be completely eaten, but often on different days or by different owls, and so would be represented in two or more pellets.

Experience on the observational areas has shown that quail remains in less than 6 percent of winter pellets (in good-sized lots) ordinarily means a fairly light horned owl pressure upon quail populations running from 30 to 100 birds per square mile. This represents losses of the sort that even well-situated populations may be expected to suffer and seems largely to take the place of the losses from age and accident which would obviously go on anyway in the total absence of predators.

TABLE 1.—*Horned owl pressure upon wintering bobwhite populations*

Area [1]	Winters	Horned owl pellets containing bobwhite remains from area	Bobwhite winter population density on area	Bobwhite winter carrying capacity of area	Percentage to which carrying capacity of area was filled by wintering bobwhite population
			Per sq. mi.	*Per sq. mi.*	*Percent*
A	1929–30	2=5.6% of 36	24	66	36.
	1930–31	4=6.3% of 64	51	66	77.
	1931–32	13=16.0% of 81	80	66	121 (insecure).
	1932–33	5=6.8% of 74	81	66	123 (insecure).
	1933–34	3=14.3% of 21	87	58	150 (insecure).
	1934–35	8=19.0% of 42	82	58+	141 (insecure).
B	1929–31	0=0.0% of 62	32+	32	100+.
	1931–32	0=0.0% of 12	54	32	169 (insecure).
C	1929–30	0=0.0% of 25	36	32	113 (insecure).
	1930–31	0=0.0% of 25	32	32	100.
	1931–32	6=9.1% of 66	63	32	197 (insecure).
D	1930–31	0=0.0% of 23	152	132	115 (insecure).
	1931–32	1=3.0% of 33	132	132	100.
	1932–33	3=9.1% of 33	160(?)	132	121(?) (insecure).
E	1930–31	5=10.4% of 48	53	40	133 (insecure).
F	1931–32	1=9.1% of 11	101	95	106.
G	1932–33	0=0.0% of 25	95(?)	103	92(?).
	1933–34	0=0.0% of 28	95	103	92.
	1934–35	4=7.7% of 52	124(?)	103	120(?) (insecure).
H	1932–35	0=0.0% of 29	191	211	91.
I	1932–33	1=7.7% of 13	75	62(?)	121(?) (insecure).
	1933–34	3=2.4% of 127	43(?)	62(?)	69(?).
	1934–35	10=5.9% of 169	69	62(?)	111(?) (insecure).
J	1932–33	15=20.0% of 75	101(?)	65(?)	155(?) (insecure).
	1933–34	7=5.0% of 139	104	88(?)	118(?) (insecure).
	1934–35	28=14.7% of 191	140(?)	90(?)	156(?) (insecure).

[1] Area *A* was at Prairie du Sac, Wis.; *B* and *C*, at Pine Bluff, Wis.; *E* and *F* at Madison, Wis.; *G* and *H* at Des Moines, Iowa; and *I* at Ames, Iowa. *J* represents the combined data from 9 areas in southeastern Iowa.

However, when quail remains occur in 10 or 15 percent or an even higher percentage of the pellets, it may be suspected that something is wrong with the quail, themselves, or that there are too many of them in the environment they are trying to occupy.

Weakness of individual birds, as from hunger, injuries, or disease, is more apt to predispose them to capture by hawks than by owls, but handicapped ones are taken by owls, also. In a number of instances, birds were killed by horned owls seemingly because they fell into unsafe living habits or were not as adaptable as they might have been in the face of danger.

For the most part, nevertheless, heavy winter predation upon bob-whites by horned owls signifies a crowded condition of the quail population, although in terms of numbers there need not necessarily be many quail present in a given area to over-populate it. Much "quail country" is inferior in quality as it exists at present and can accommodate but a very limited population, often a population far lower than that which the public may think ought to be there.

It should be recognized that a population of 10 birds in an environment having a carrying capacity of 5 per square mile is crowded just as truly as is a population of 300 in environment having a carrying capacity of 150 per square mile. Less conspicuous mortality will be suffered by the smaller population, but the position of the 5 extra birds seems to be about as insecure as the position of the 150 extra ones; where populations exceed the capacity for accommodation set by the environment as it stands, the precarious position of the excess birds simply invites predation.

Much quail environment is overpopulated by autumn as a natural consequence of the season's increase of young birds and the annual change from fall to winter conditions of vegetation. Further shrinkage of carrying capacity may follow the clearing away of brush or the burning of vegetation by farmers; fall plowing; clean harvesting; close grazing, etc.; or emergencies that may evict populations or parts of populations from environments that otherwise would have accommodated them. Deep snows, in particular, by covering up the food in many parts of an area, may cause concentration of birds in other places where food may still be had.

On that part of area A, table 1, where most of the 1934-35 predation of horned owls upon quail took place—8 of 42 pellets containing quail remains—hungry quail kept drifting in from the outside throughout the winter.

This tract of land had a carrying capacity of around 53 bob-whites, as calculated on the basis of the numbers that had successfully wintered there in previous nonemergency years. As nearly as the 1934-35 story could be pieced together from almost continual field studies, 72 quail started the winter and 50 were surviving by spring; but in the meantime there had been much movement in, some movement out, and a mortality that could be fairly closely determined at 54 birds, or a loss exceeding the number that wintered.

As long as the quail occupying this tract filled it up only to the limit of its known carrying capacity, the population suffered negligible losses from predation, from horned owls as well as from other resident predators. But whenever the environment became filled with quail past carrying capacity, the surplus birds soon departed (or their equivalent number did), or increased pressure from enemies cut the population down to the level of carrying capacity again.

Exactly why the strongest environment can apparently take care of only about so many wintering quail from year to year is not clear.[10] Intolerance of the quail themselves toward too much crowding doubtless enters into the equation. One effect of general overcrowding is the forcing of some coveys or groups of birds into locations that are plainly unfavorable and of others into a dismal round of wandering from one uninhabitable or filled up covert to another. Badly situated coveys, whether they keep moving or attempt to station themselves in inferior environment, bear the brunt of pressure from enemies.

The reader may perceive from table 1 that insecure populations are not always heavily preyed upon by the horned owls living in their vicinity. This does not mean, however, that the insecure populations are no longer being preyed upon; it usually means that some creature besides horned owls is doing the preying. One thing that seems characteristic of insecure populations is their common vulnerability to a number of different predators, even predators differing greatly in prowess and hunting tactics.

It doesn't seem to matter much what, or, within limits, how many predators may do the preying as long as the basic insecurity of a wintering quail population continues unrelieved—at least, this seems to be true in the north-central States' quail range.

A few horned owls seem to eliminate the vulnerable surplus of a wintering quail population about as effectively as many horned owls; and, in the absence or scarcity of horned owls, the reduction seems to go on anyway through the medium of other predators. Marsh hawks, foxes, and house cats, compared with horned owls, are very inefficient winter enemies of bobwhites; and clumsy Buteo hawks, small owls, and dogs are lesser enemies, indeed; but these and even rodents, pheasants, poultry, and the quail themselves may kill quail as the opportunities multiply with biological unbalance.

The generalization appears to be sound that if the bobwhite suffers severely from winter predation there is a good reason for it. McAtee's contention that predation tends to be indiscriminate in action and in proportion to population [11] is supported by the Iowa and Wisconsin data on predation and wintering quail, as relates to the net effect of predation upon excess populations or populations otherwise rendered vulnerable. Any relief that vulnerable populations may gain from a specific enemy (always excepting man) seems more than likely to be counteracted in the end by increased pressure from other enemies, including some not commonly classed as enemies, or classed as enemies only under extreme circumstances.

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[10] Errington and Hamerstrom, op. cit., footnote 5.

[11] McAtee, W. L., Effectiveness in nature of the so-called protective adaptations in the animal kingdom, chiefly as illustrated by the food habits of Nearctic birds. Smithsonian Misc. Coll., vol. 85, no. 7, 1932.

As the reader may see from table 2, spring losses of quail from horned owls may be heavy at times, notably when rather substantial populations have wintered that are close to the carrying capacity of the land. There may be in late March and April an increase of pressure by the owls upon bobwhites decidedly greater than the bobwhite winter losses might have led one to expect.

TABLE 2.—*Horned owl pressure upon spring and summer bobwhite populations*

Area	Season	Horned owl pellets containing bobwhite remains from area	Bobwhite spring population density on area	Bobwhite winter carrying capacity of area	Percentage to which carrying capacity of area was filled by spring bobwhite population
			Per sq. mi.	*Per sq. mi.*	*Percent*
	Spring, 1930	0=0.0% of 36	22	66	33
	Spring, 1931	2=5.0% of 40	47	66	71
A	Summer, 1931	0=0.0% of 39	47	66	71
	Spring, 1932	13=12.0% of 108	58	66	88
	Summer, 1932	0=0.0% of 38	58	66	88
	Spring, 1933	3=12.0% of 25	68	66	103
C	Spring, 1931	0=0.0% of 24	31	32	97
	Summer, 1931	0=0.0% of 65	31	32	97
D	Spring, 1931	0=0.0% of 13	128	132	97
	Spring, 1933	3=12.5% of 24	132	132	100
E	Spring, 1931	1=2.6% of 38	32	40	80
	Summer, 1931	2=4.2% of 48	32	40	80
G	Spring, 1933	3=4.4% of 68	90(?)	103	87(?)
	Spring, 1933	8=6.7% of 118	62	62(?)	100(?)
	Summer, 1933	9=4.9% of 182	62	62(?)	100(?)
I	Spring, 1934	2=3.9% of 52	41(?)	62(?)	66(?)
	Summer, 1934	2=12.5% of 16	41(?)	62(?)	66(?)
	Spring, 1935	0=0.0% of 60	22	62(?)	35(?)

The owls, to be sure, have large and hungry young in their nests and hence a need for more food, but the connection here is not so clear as it might appear at first glance. The quail seem vulnerable also to the attacks of predators that do not have young to feed at this season or otherwise have any greatly increased need of food. Then again, much of the spring quail loss from predation occurs when there is presumably more food available for predators than there was in late winter, such as the hosts of migrating or newly returned birds, various animals that had been in hibernation or had not been so accessible during the colder months, etc.

A possible explanation seems to be that the spring rise in vulnerability shown by some quail populations is associated with the increasing unrest of the quail as their own breeding season approaches. One of the manifestations of an overpopulated condition is increased friction among the quail themselves; and it may be that the intolerance and strife and excitement of mating may have the same effect as overpopulation in making the birds vulnerable to predator attacks. In other words, a carrying capacity just sufficient to winter a certain population level with evident security and com-

paratively little quarreling may not be sufficient to accommodate the
same population at the height of the period of sexual adjustment.

The 388 summer pellets of table 2, which were obtained almost
entirely through the tethering [12] of owlets in the quail observational
areas, contained remains of adult quail in 13. No recognized traces
of young bobwhites were discovered in pellets collected as late as
August nor amid the prey debris at feeding places of the owls.
Remains of immature bobwhites have been found in fall horned
owl pellets, however; but pellets of unquestionable horned owl origin
are so difficult to procure at this season that the scanty data do not
justify conclusions.

According to indirect evidence, the extent and effect of summer
predation upon young bobwhites are both variable. The bobwhite
tries to bring off one annual brood and may make repeated nesting
attempts if the earlier egg clutches are lost or abandoned. One
bird of the pair, usually the female, does the incubating; but if that
bird is killed, the mate may take over incubation duties and com-
plete the hatching of the clutch or may find another mate and start
over again.[13] Both birds are active and capable in caring for the
young, and either one may perform this function alone, if neces-
sary. In this way the species is somewhat safeguarded against
excessive interference with reproductive endeavor through preda-
tion. The horned owl is scarcely under suspicion as a predator
upon quail eggs, but surely some of the pressure it exerts upon sum-
mer adults is borne by nesting birds.

On the southern Wisconsin observational areas, the rate of in-
crease of bobwhites from breeding stock seems to be influenced by
how much the habitable environment is filled up to begin with;
if the environment is pretty well saturated by the adult popula-
tions, the chances of many young reaching maturity seem to be cor-
respondingly diminished.[14] Nature is ever prodigal with the lives
of young animals and becomes more so as population densities rise
to the degree that individuals are compelled to live at an increasing
disadvantage.

Then, as winter comes and finds adult populations at their highest
level of the year and carrying capacity shrinking with the dropping
of leaves from trees and brush and the drying up of weedy vege-
tation and the falling of the first snows, quail remains may be rep-
resented more and more in the horned owl pellets. And, as winter
settles down and the status of the quail may be further compli-

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[12] Owlets are tethered in the vicinity of their nests by means of chains and leather
anklets, in order that records may be kept of the food brought them by adults after the
time that they normally would have left—see Errington, P. L., Technique of raptor food
habits study. Condor, vol. 34, pp. 75–86, 1932.

[13] Stoddard, op. cit., footnote 4.

[14] Errington and Hamerstrom, op. cit., footnote 5.

cated by crises that evict birds from some habitats and crowd them into others or drive starving remnants from one place to another, the cycle of mortality starts over again; and the birds continue to be preyed upon largely in proportion to their vulnerability, if not by horned owls, then by something else.

Thus may be concluded this résumé of the relationship of one predator to one prey species as it has been worked out in one region over a period of years. It does not necessarily typify predator-prey relationships, though some others seem to be similar. Other relationships are apparently quite different; still others consistently defy scientifically acceptable analysis; and, of countless others, it can only be said that virtually nothing is really known of them.

This writing is not intended to be a brief against all attempts to control predators for economic or conservation or other legitimate purposes. It does not imply that no control of any predators is desirable in the conservation of the bobwhite, nor that control of horned owls may not be important in the protection of species other than bobwhite, nor even that under some conditions bobwhite conservation may not be aided by the control of horned owls.

It does submit that predator control is frequently emphasized beyond any existing justification. Too often the persecution of predators—however futile—is the one thing that is stressed in the name of conservation, whereas measures of the utmost merit are barely toyed with, if not disregarded altogether. When predator control is only blind, ruthless suppression of any and all flesh-eaters, or alleged flesh-eaters, with no heed for the status of rare or endangered species, it surely ceases to be the public interest and should be discouraged the same as any other wasteful practice.

The interrelationships of predation are exceedingly complex and variable, and how much they will ever be understood is problematical. The accumulating evidence seems to suggest that many prey populations are constituted to withstand far more pressure from enemies than they ordinarily get; and, within the restrictions imposed by their habitats, seem to be mainly self-limiting and self-adjusting in numbers. The impacts of predation, then, are absorbed by at least some populations that seem to be resilient chiefly according to their needs. The trimming down by predation of excess populations that must disappear, anyway, is incidental. It should not be regarded as a threat to the permanent nucleus, which, barring drastic change in environment, will continue to occupy all livable quarters and produce the usual annual surplus. The surplus is strictly temporary, and generation after generation is frittered away. Whether taken by predators or otherwise lost, the surplus must disappear; population sooner or later coincides with carrying capacity.

THE GORILLAS OF THE KAYONSA REGION, WESTERN KIGEZI, SOUTHWEST UGANDA [1]

By Capt. C. R. S. Pitman, D. S. O., M. C., C. M. Z. S.

[With 6 plates]

The occurrence of gorillas in the Kayonsa region of Uganda has been known for many years, but until recently opportunities and facilities for investigating this interesting locality have been lacking. The opening of the road to Rutshuru (Belgian Congo), from Kabale (Uganda), however, has made it more accessible, and the extension of prospecting activities into the forest itself, rendered a visit imperative to ascertain, from a conservation point of view, the extent of the disturbance to which the forest is being subjected, and what effect this is having on the gorillas. These notes are based on knowledge acquired during two brief visits, each of a few days' duration only, made respectively in November 1933 and February–March 1934.

The long-haired mountain gorilla (*Gorilla gorilla beringei*), of east-central Africa, has in recent years had an excellent press, and around the question of the adequacy of the measures taken for its protection and perpetuation much controversy has raged. It is unnecessary, therefore, to refer in detail to the generally accepted description of habits and attributes of the mountain race, which will be discussed where relevant in connection with the Kayonsa representatives.

It must be realized before proceeding further that this is not an endeavor to create a new race of gorilla, though on account of its markedly diverse habitat, food, and habits, the Kayonsa species may well have developed structural characteristics differing from those of its relatives in the more elevated volcanic region. A little more than a decade ago it was suggested that different races of gorilla probably occurred on each of seven (a startling total) adjacent, extinct volcanoes of the Mufumbiro (or Birunga) mountains—an extravagant and preposterous claim.

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Sir Frank Colyer, K. B. E., of the Royal College of Surgeons, and an eminent dental surgeon, who has for years been studying the dental diseases and dentition of wild and domestic animals in relation
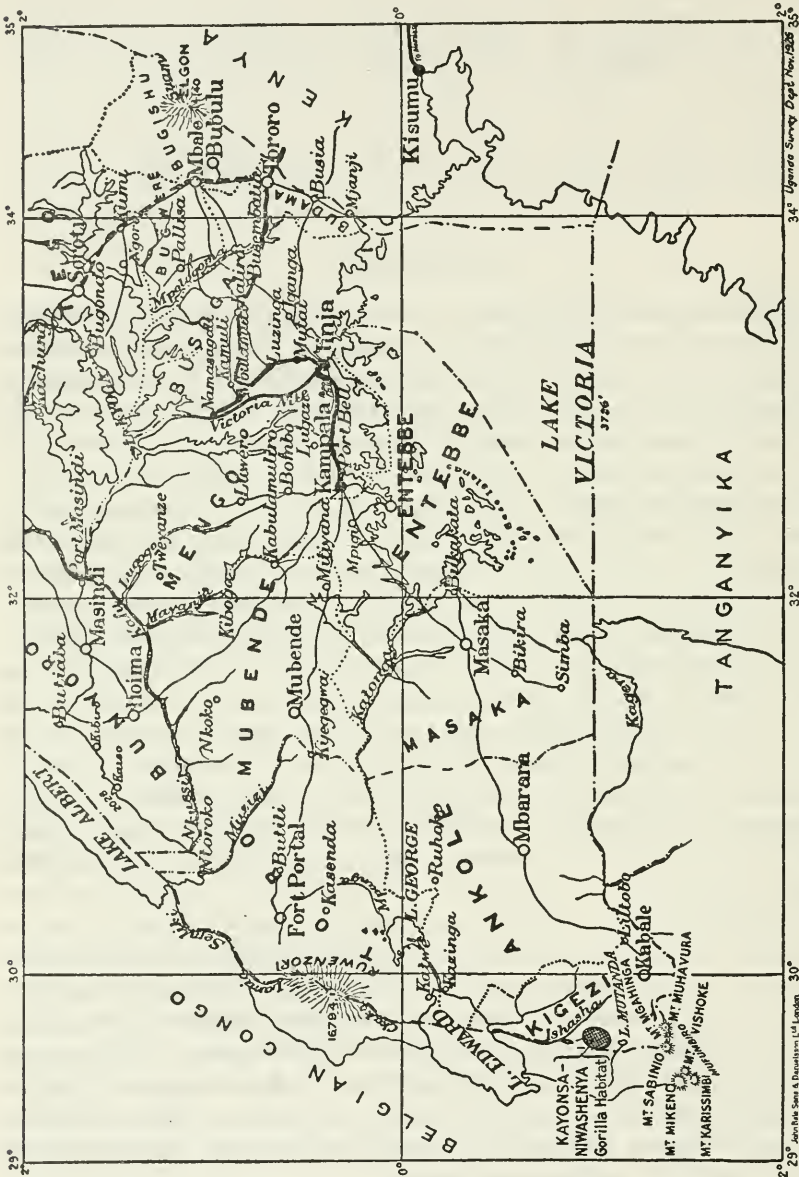

FIGURE 1.—Map showing the Kayonsa-Niwashenya gorilla habitat.

to those of the human race, has made an exhaustive examination of a very large number of gorilla skulls, which revealed that those from localities in which the bamboo is absent from the gorilla's habitat are

readily recognizable owing to the freedom from appreciable spacing between the teeth. This spacing is a result in infancy of food packing, tough fibrous pieces of the bamboo shoots becoming wedged between the teeth and gradually pushing them apart. In due course, this has developed the spacing as a constant, and possibly now inherited feature.

This difference, slight though appreciable, is scarcely a basis for satisfactory separation but it does indicate that the mountain gorillas respectively in the widely different, florally and climatically, regions (*a*) west of Lake Kivu, (*b*) southwest (or westerly) of Lake Edward, (*c*) the Birunga Mountains, and (*d*) the Kayonsa may to a certain extent differ from each other. The representatives from west of Lake Edward have been separated from *beringei* under the attractive and descriptive title of *rex-pygmaeorum*,[2] though the material on which the separation is claimed is scanty. With adequate comparative material it might be possible to separate racially the typical mountain gorilla of the excessively humid bamboo and hagenia-covered mountain slopes of the elevated Birunga Mountains from those of the drier localities from which the bamboo is absent. If such is the case, then the Kayonsa representative will possibly be found to be an extreme form of the latter as a result to a certain degree of environment, but particularly owing to a general absence of the juicy vegetable food of which the gorilla is so fond.

There unfortunately being no material available for scientific study, with the exception of an old skull from this region, and little likelihood of any being procured at any rate in the near future, the status of what may prove to be a specialized race has to be based mainly on assumption.

Ecological facts which are definitely known, and which show great divergence from the Birunga zone, are:

(1) There is in the Kayonsa a complete absence of bamboo, wild celery, dock, and similar juicy-stemmed plants such as abound in the humid, high altitudes, forcing the gorilla to confine its diet to a mixture of leaves, berries, ferns, the tender fronds of tree-ferns, parts of the wild banana stems, and leaves, and fibrous bark peeled off a variety of shrubs in the undergrowth. Examples of some of these botanical specimens submitted to the British Museum (Natural History) for expert determination which have been identified include

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[2] *The name of the Kayonsa gorilla.*—Captain Pitman has kindly sent some skulls of the Kayonsa gorilla to the British Museum (Natural History), where I have been able to examine them. In the shape of their nasals, the possession of a distinct masseteric knob on the zygoma, and the position of their incisive teeth, they perfectly agree with the gorilla from the Birunga volcanoes, and can easily be distinguished from the races living west of the central African Rift, *G. g. graueri* Matschie from the isolated forest at Sibatoa's, northwest of Lake Tanganyika, and *G. g. rex-pygmaeorum* Schwarz from the east-central forest.—ERNST SCHWARZ.

the fern *Asplenium sandersonii, Piper capense*, representatives of the tribe Helianthoideae of Compositae, and a species of *Acalypha* (Euphorbiaceae).

(2) Owing to a lack of what apparently are normal food constituents the gorilla has become more enterprising in search of food, and in consequence climbs trees freely to a known height of at least 50 feet. Further reference to this is made later.

(3) The "beds" of the Kayonsa gorilla are large platforms built in the trees, and often at a considerable height above the ground. The subject of these "beds" will be dealt with more fully in due course.

Finally, in connection with divergence is the question of habitat, which is really the crux of the situation, for nowhere does it exceed 8,000 feet in height, the altitude varying between 6,000 and 7,900 feet.

Little is known of the greater part of the area marked on the map "Impenetrable forest", as there is no population and no means of access. On the hill and ridge tops, once attained, progress is fairly simple along the numerous paths made by the gorillas and bush-pigs, but abrupt climbs up the hill slopes, sometimes for 1,000 feet and over, and passage through the dank valleys choked with dense undergrowth is only possible if a file of the local populace armed with home-made billhooks, an indispensable of their everyday equipment, lead the way. There are some stands of fine trees, particularly noticeable being a species of *Podocarpus*, at the higher elevations; but, on the whole, except for here and there a forest giant of outstanding size, the timber is disappointing and, in the portion (the southern) of the forest visited, suggestive of comparatively recent origin.

The various photographs of the forest give an accurate idea of its grandeur, density, and beauty. To obtain these pictures it was necessary to fell several trees and clear away large patches of secondary growth to afford an uninterrupted view of the opposite hillslope. The densely tangled undergrowth, securely bound and interwoven with brambles and a variety of tough creepers, for man is absolutely impenetrable, but through it a 6-foot gorilla weighing 400 pounds creeps with ease and without making a sound. One of the photographs reveals a scarcely perceptible hole in the tangled vegetation below the tree-ferns through which, not long before, a full-sized male gorilla had emerged silently and unexpectedly upon two European prospectors: both parties were equally surprised!

The great feature of this forest region is the abundance of graceful tree-ferns; many are fully 20 feet in height, while a few reach the amazing height of 30 feet. As this region constitutes neither tropical nor rain-forest but can be described as typical montane forest, the tree-ferns are to be found in their luxuriant abundance principally

in the humid valleys, on the lower and more sheltered hillslopes, and, in fact, in any sheltered locality either on the tops or at the sides of the ridges. Tree-fern thickets, with hundreds of fallen thorny stems lying in all directions which cannot be removed, but have to be surmounted, provide some of the most difficult going under general conditions which are notoriously exacting. An hour or two amongst the tree-ferns in a valley bottom will tax one's patience to the utmost, and prove arduous to even the fittest and strongest, though the bare-footed pygmy guides negotiate these nightmare places with the agility of monkeys.

On the main forest outskirts, and on hillslopes and hilltops on which advancing settlement and cultivation have systematically destroyed the trees, there is an abundance of bracken. Plate 5 portrays a steep hill, in shape like an inverted pudding bowl, a few hundred feet high, densely covered with bracken. These bracken-covered slopes provide wonderful refuges for the little red (forest) duiker (*Cephalophus nigrifrons kivuensis*), a creature of about 30 to 40 pounds in weight, which is rarely seen. Specimens are only likely to be acquired with the aid of the local inhabitants, who occasionally destroy a few when hunting the destructive bush-pig, whose downfall is encompassed with well-trained dogs and nets. Some localities show strikingly the sequence of events from the initial deforestation to cultivation.

The situation was carefully examined in this connection to ascertain whether undue deforestation was taking place, and whether there was a likelihood of the gorillas thereby being adversely affected. As far as could be gaged in the limited time available for investigation, the destruction of forest is not on an extensive scale, and actually is taking place away from, and not toward, the gorilla haunts. The forest region to the east of the Kishasha River is a gazetted forest reserve and, in consequence, not open for human settlement. There is little likelihood in the immediate future of serious conflict between man and gorilla in the dense uninhabitable valleys to the west of this river and in the vicinity of the Belgian Congo border, where the two encounters shortly to be described took place.

At the time of the respective visits, based on information received from the local Wambutte, and from a prospector who knew the area intimately after operations lasting 18 months, it was calculated that this western area harbored 40 to 50 gorillas. Many of these, if not all, at certain seasons of the year, are believed to cross to the elevated forest reserve to the east of the Kishasha River, so that even if the lapse of time did see undue encroachment on the part of the human population in the western habitat, the gorillas would still

have unlimited sanctuary in the east to which they could satisfactorily migrate.

The abundance or scarcity of gorillas in the vast eastern, impenetrable region is at present unknown, though it is quite definite that on the hills of Mpororo and Niguru at the southern extremity, there were several gorilla troops, believed to total about two dozen individuals, at the same time that the western estimate was made. Also, in the unvisited northerly region astride the Kishasha (or Irwi) River, where the rainfall is greatest, a reliable informant records numerous gorillas; and therefore the claim that there possibly exist at least 80 of these magnificent anthropoids in the Kayonsa and impenetrable forest region does not appear extravagant.

Normally the troops vary in size from five to eight or nine, and consist of one full-grown male, the father of the flock, and, according to the size of the band, two or three females, the remainder being juveniles of varying sizes. In the western region there is apparently one huge troop permanently of the abnormal dimensions of nearly two dozen. As I had unsolicited information about this large, and I imagine truly terrifying, troop from no fewer than three reliable and independent sources covering a period of 2 years, there is no reason to doubt its existence. It would be most interesting to discover the exact constitution of so large a troop, and whether it is limited to one adult male only. Actually I missed by a few hours the opportunity of having a glimpse at this horde. The indispensable Wambutte spying out the land for me prior to His Excellency the Governor of Uganda being introduced to his humblest subjects, encountered far away and unexpectedly this supertroop, and too late for me to have a hope of making contact before darkness fell, came back gibbering with excitement to tell me of their great adventure.

Before further casual allusion to the Wambutte is made, it will be best to record the reason for the presence of any Wambutte, true pygmies, in Uganda, when this name is usually associated with the Ituri forest to the west of the mighty Ruwenzori range, and the elevated mountain ridges on the Belgian Congo side of Lake Edward. The half-pygmy Batwa of the Mufumbiro volcanoes, those domiciled in the Belgian zone of the Parc National Albert, being regarded as part of the natural fauna(!), have long been familiar to me. But, on first acquaintance with the little men of the Kishasha valley, I was extremely puzzled by the unvarying reference of the local Bachiga to the Wambutte, instead of the Batwa. These little folk, on being interrogated, hotly denied any relationship with the Batwa of the volcanoes, and emphatically affirmed that they were true Wambutte. On being further questioned to account for the isolation of their little group—in addition to the aged and infirm, the tally of adult males is now about nine—so far away from the Wambutte

of the Ituri, they proudly assured me that this was the original home of the tribe, and that when all the others migrated west, their forbears remained behind.

It is a fascinating problem which can never be satisfactorily elucidated, but it is possible, and not improbable, that the curious isolation of these Wambutte and this gorilla habitat is a direct result of the terrific upheaval, evidently a cataclysm on an unprecedented scale, in the now-devastated region between the Niwashenya ridge and Mufumbiro, which once must have been extraordinarily fertile and humid. Then the all-conquering lava flow, amongst the numerous catastrophes caused, dammed the deep valley now represented by Lake Mutanda.

But, whatever the correct solution there the little folk are in splendid isolation, constituting an interesting anthropological puzzle. A previous allusion to the Wambutte is qualified with the adjective "indispensable", no distortion of fact, for without their whole-hearted cooperation and assistance, never a glimpse of a gorilla, except by sheer accident, is one likely to get. It is true that by frequent wandering along some of the well-defined tracks, which are easily followed, on the fringe of the gorilla haunts one may both hear and locate a troop, but it is a very different matter, quite hopeless, to try to get to close quarters unassisted and unguided through the maze of dense undergrowth covering what probably proves to be a succession of exceptionally abrupt ascents and declivities before there is a chance of attaining one's goal.

The Wambutte, who have every respect for, though are not frightened of, these great apes, are therefore their best guardians, for if instructed to refuse aid to any stranger without the express permission of their chief as directed by higher authority, it will not be possible, or at least highly improbable, for the unauthorized to interfere with the reasonably peaceful Kayonsa gorilla. The Wambutte know full well the absolute protection conferred on this species and the penalties attached to any breach thereof, and are not anxious to become involved in an unfortunate incident. Far less are they prepared to infringe the instructions forbidding them to render assistance to unauthorized strangers. And, it must be remembered that if these pygmies do not want to do a thing they will not—coercion is quite out of the question.

After my first visit in November 1933, when absolutely satisfied that the gorilla enjoyed fully the immunity from molestation which the law conferred, though somewhat disturbed by the penetration of prospecting parties further into their haunts, instructions were left with the local chief to insure freedom from unauthorized disturbance. There was no doubt of the faithfulness with which these instructions

were carried out, for when in January 1934, Mr. R. Akroyd, who conducted a British Museum expedition for the purpose of collecting botanical material for the gorilla group to be erected in the Natural History Museum at South Kensington, turned up at my old camp, he was regarded with open distrust by the local inhabitants and was never aware of the existence of any Wambutte, although their location was almost in sight of his tent. He did see a small gorilla band on an elevated hillslope, opposite to and high above his camp. Laboriously he struggled to the point where it had been observed, but all he found were a few lumps of chewed fiber which had been expectorated by the feeding apes.

The pygmies are an essential concomitant to successful gorilla observation, and without their assistance to the stranger the great anthropoids can enjoy to the full the protection they so thoroughly deserve. Protection, pygmies, and the local Bachiga suggest a few remarks on the subject of ferocity.

First, in order that I may not be accused of undue bias from the point of view of the protection of one of Uganda's rarest and most interesting mammals, I will quote the unsolicited testimonial of a prospector who regarded the gorillas as quite harmless. He says:

I have been prospecting in the impenetrable forest (Kayonsa-Kigezi) and I thought that you might find the following experiences with gorillas of some interest.

My work has at times taken me into places where they were in residence. I have found them very peaceful, and it is possible to get within 20 feet of them.

I have only been attacked once, by an old male, but he was not a savage brute. He was first attacked by my dog and his sole aim was to catch the dog, otherwise it could have easily caught and killed my "boy."

The gorilla "beds" are built from 5 to 20 feet high in the trees, each bed from approximately 10 feet to 10 yards apart. The "beds" consist of bent-over branches, with a superficial extent 3 feet by 2 feet approximately.

As far as I know they travel about in bands of about six to eight. They do not make much noise, but just grunt. I maintain that unless provoked they are docile.

I have seen about 80 during a long period while prospecting in the impenetrable forest. The gorillas sometimes raid the nearby *shambas* (gardens), but I have never heard of them attacking the natives, and the natives leave them alone except to chase them away from their property.

This frank statement exposes definitely the fallacy of exceptional ferocity, a state of affairs it was believed existed and which was based on second-hand information. In my imagination the Kayonsa gorilla was an unapproachable brute, wickedly tempered from constant conflict with the local natives, whose crops it habitually raided, a creature whose company was better avoided than sought. No one of reasonable intelligence could claim that according to circumstances the gorilla is not exceedingly dangerous and ferocious.

But, around the male gorilla, on account of its enormous size and strength, coupled in recent years with frequent lapses from grace provoked by unnecessary and undue interference, there has been woven, and unfortunately published, a fantasy of inaccuracy and exaggeration, so much so that the very homely old male is visualized as an object of dread. The male gorilla, as the family head, is most solicitous for the welfare of his wives and children—a very human trait, and on the threat of danger unheeding of his own safety accepts full responsibility for the well-being of his charges. Can he be blamed?

If the danger is real the females and young are sent off, while father waits to take on all comers until satisfied that the remainder of the band are out of harm's way. Sometimes, when the danger is sudden and overwhelming, the youngsters are sent up trees to hide till the trouble is over. It is strangely reminiscent of the records of some of the early African explorers relative to tribal customs. When the womenfolk were to be seen busily engaged in their usual vocation in the precincts of a village or kraal, all was well, and no hostility contemplated on the part of the local inhabitants. But an absence of women and children was interpreted as unfavorable, signifying that they had been removed to a safe place in order to enable the warriors to fight unhampered. And so it is with the old male gorilla, for as soon as he bids his family seek safety, he is out for mischief, though without direct provocation is unlikely to attack. There are black sheep in each fold, and exceptions to every rule, and solitary examples, both male and female, which have probably been outlawed for a very good reason, have been known to be abnormally aggressive.

The father of a band is liable to be most demonstrative when it contains very small juveniles. The demonstration must be truly fearsome and nerve-racking, and I am thankful I have not yet experienced it. Eye-witnesses, who have had the strength of mind and temerity to stand firm to a so-called charge and refrain from shooting, have described to me how the gorilla suddenly pulls up to stand upright and seemingly towers above the intruder. A pause—he turns and shuffles away. Graphic and thrilling accounts of these demonstrations, some faithfully perpetuated in picture, will be found in Du Chaillu's "Equatorial Africa", descriptive of many journeys of exploration in West Africa between 1856–59. I never tire of reading these fascinating narratives, but what has ever filled me with unbounded admiration is the fearlessness and pluck of this well-known explorer-naturalist who, armed with a single-barreled muzzle-loader, habitually refrained from firing at the demonstrating male, allowing him time and again to arrive almost within grasping distance.

Compare this with the present day and the investigator backed by a high-power modern double-barreled rifle, capable with a soft-nosed bullet of dealing a shattering blow—practically infallible. Then read the awful tales of superferocity served up for world-wide consumption by the very people so well armed that they can interfere and disturb as freely as they like in absolute safety.

And, if the gorilla, suspicious and resentful of constant interference and undue disturbance, is no longer content with demonstration, but is prone to carry home his "charge", who is to blame—the gorilla or the persistent disturber? With little practical experience one cannot dogmatize, but if that limited experience is backed by the knowledge acquired by reliable eyewitnesses, as it is most emphatically, then it can be unhesitatingly claimed that, like most wild creatures, the gorilla normally is peaceably disposed and not aggressive. More than most, possibly, is this the case with the Kayonsa representative, for, owing to constant close contact with human settlement and the wandering charcoal-burners who operate in the heart of its western haunts, it can be regarded as almost semidomestic, while I am reliably informed that at times the old males are absurdly contemptuous of the local populace. It is a striking example of the familiarity which breeds contempt.

As far as could be ascertained, and in spite of what had been previously asserted to the contrary, the Kayonsa gorilla is not guilty of frequent crop-raiding, at least so the local natives assured me. It is true that the gorillas often feed in the vicinity of cultivation, but the attraction is mainly the occurrence of various species of nourishing weeds which grow to exceptional size on abandoned plots. The local Bachiga (who can blame them?) very naturally object to the proximity of these awe-inspiring beasts, and usually try to drive them away. It is then that the males are most contemptuous of human effort, and the females and young having been sent off, the old gentlemen move only when it suits them to do so. The Wambutte are extremely tolerant of the gorillas, but not so the other local natives, who would readily endeavor to exterminate the lot, were it not for the fact, of which they are well aware, that these splendid animals are absolutely protected by the Government. It can be realized, then, that the principal human enemy of the gorilla is the camera-man and pseudo-investigator, who disturb flagrantly and unnecessarily, then irritate, and finally have to take life in "self defense."

In the minds of many who should know better, the gorilla is classed as a dangerous, ferocious beast, for "if molested it endeavors to defend itself!"

The general proximity of this gorilla habitat to human settlement has resulted in the presence of human beings having little disturbing

effect on the gorillas. In consequence, the prospecting, which incidentally has penetrated only the extreme southerly portion of the forest, cannot be said to have caused undue disturbance. Prospecting on a systematic scale has taken place in the forest, particularly in the valleys, in the vicinity of the high hills, Niwashenya, Niguru, and Kasatora. When I was in that neighborhood at the beginning of November, there were frequent complaints from isolated pairs of natives digging pits that gorillas were too close to be pleasant. Even a lot of blasting seemed to have little other effect than to scare them away temporarily.

The previous brief reference to gorilla beds can be amplified considerably. Several were measured and found to vary in size from 3 feet by 2½ feet to 4 feet by 3 feet, the latter presumably the sleeping quarters of the big males. The thickness of the bed platforms ranged from 8 to 15 inches. Three groups of beds—many more were seen—were critically examined. The lowest bed was 6 feet above the ground, the majority 10 feet or over, and four (two in one group and one in each of the others) between 20 and 25 feet. In one group of four, the beds, sited in a rough circle around a forested hollow at the top of an elevated valley, were respectively at intervals of 10, 15, 30, and 50 paces in the circle, and all plainly visible to each other. Groups of beds seen in trees on the forested slopes of valleys were also sited so as to be clearly visible from each other. As in the case of the volcanoes' representatives these beds are singularly filthy, and the edges often festooned with excrement.

In the Kayonsa tree-climbing is customary, and beds normally [3] constructed well above the ground. It is probable that the same platforms are used on several consecutive nights.

The highest bed seen was nearly 50 feet above the ground, and evidently constructed the previous night, but fortunately the picture taken by His Excellency the Governor of Uganda does not do justice to the subject. It would have been more effective had a Wambutte been perched on the edge of the platform. Its foundation consisted of sturdy, upright tree-tops as much as 2½ inches in diameter, which had been snapped like matchsticks. As the description of this novel method of bed construction is certain to provoke criticism and unlikely to pass unchallenged, it is fortunate that His Excellency and two of his staff should have been present when the 50-foot bed was observed, as their corroborative evidence is irrefutable.

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[3] During 1936, the Acting Game Warden, Capt. R. J. Saimon, viewed some of the Kayonsa gorillas and found them amiably disposed. There is nothing, as a result of his visit, to add to these comprehensive notes, except that he found "two big groups of nests, of different nights, all on the ground with no overhead protection apart from the lean-to effect of big tree-trunks."—C. R. S. P.

On this occasion a troop of eight had been at least 36 hours in the particular valley visited, and but for the mildly disturbing effect of our party might have remained there another couple of days. Undisturbed, there was no apparent intention of their leaving the locality, and during a period of several hours the troop was feeding in an extremely tiny area. But in this instance there had been a striking deviation from what is imagined to be the normal sleeping procedure, for, with the exception of the occupant of the lofty bed previously mentioned, all the animals had slept on the ground

The sleeping quarters were at the base of a large tree surrounded by a dense tangle of undergrowth. For about two-thirds of the way round the tree base a broad, shallow trench a few inches in depth had been scooped out of the dry soil, which constituted a wonderfully cozy bed and refuge, effectively screened and protected by the almost solid canopy of interwoven stems and matted foliage. At each end of the trench and along its outer perimeter was banked up the scooped earth and a pile of rubbish such as dead leaves and twigs. It was impossible to conjecture in what attitude these gorillas had slept, but the containing bank may have served both for protection and comfort. This communal bed was as filthy as usual, and from the freshness of the excreta had not been used for more than one night. One of the droppings was so immense that my gun-bearer naively remarked that it looked more like an elephant's. This dormitory was in the center of the small area in which the troop was feeding. The treetop bed some 50 yards higher up the hillside most certainly overlooked the ground shelter, though of its occupants presumably nothing could have been seen.

This terrestrial sleeping-place conclusively upset any theories previously held as to the whys and wherefores of the tree-building habit, to account for which no satisfactory explanation can at present be advanced. A spell of dry weather may have induced ground sleeping, or an expectant mother unable to climb satisfactorily may have required protection; but if so, was it the old male up the tree, and why? If a birth was imminent his women-folk may have made him keep his own company, though he would still act as their guardian by day. It is all very intriguing. Tree-climbing for food is readily understandable, but tree-climbing to go to bed is another matter, and requires explanation.

Beds in trees are suggestive of protection, not comfort, but there is no apparent reason why such security is necessary. It cannot be for fear of leopards for there are as many, and possibly a great deal more, on Mufumbrio. Locally, no tales were heard of exceptional abundance, and the leopard theory is untenable. In the past there may have been frequent incursions of lions from the Lake

Edward plains or elsewhere, a phenomenon which might have driven the gorillas to seek safety in the trees. One day by chance one may happen upon the correct solution. Climatic conditions are unlikely to be the controlling factor, for the ground, however damp, does provide a measure of warmth and shelter, while the elevated "perches" in the trees are often exposed and must be exceptionally cold. What then?

There is one other factor which merits consideration. Can the destructive bush-pig be responsible for this extra solicitude for protection? The nocturnal bush-pig, with which this region swarms, when foraging in truculent droves is no mean antagonist, and is quite capable of routing a gorilla troop by sheer force of numbers. Is this the answer to the riddle? Time alone can tell.

In order to convey an idea of the exacting conditions under which gorilla investigations are made, a graph (fig. 2) is shown of the route followed—the altitudes being recorded by pocket aneroid—in terms of ascents and descents to the approximate time factor. And, as previously explained, the going nowhere is straightforward. When one does happen to travel along the side of a hill or round a reentrant and expects a little relief, the so-called path is almost invariably on a slant of 45 degrees, and hedged in closely with tall grass and scrub.

The most profitable and comfortable way of observing the Kayonsa gorillas is to let the pygmies, who are experts, go out first to locate them. Normally a troop does not move far in the 24 hours, often remaining 3 to 5 days in a small valley, and sometimes being found on 3 consecutive days practically in the same spot; once located, if it is too late to make contact that day it is unlikely to be far away the next.

In order to experience the difficulties in progression one has to expect, as well as to exercise gradually one's hill-climbing muscles, it is quite sound to go out previously on reconnaissance. But to join the pygmies in the initial efforts to locate a troop is not advised, as one is merely a hindrance to these agile little people. A good walker can satisfactorily take on the Wambutte on the level, and so he ought with his big stride, but it will take an exceptionally active and seasoned white man all his time to keep in sight of his little guides as they make prolonged ascents at their normal pace.

And what pitying scornful glances they cast at the perspiring *mzungu* (European) painfully toiling upward and lagging far below. The altitude, 6,000 feet to 7,900 feet, naturally also adds to the difficulties of strenuous climbs, and it takes several days, if then, to acquire what one hopes is goatlike agility, and to ascend

abrupt hill sides without the lungs trying to burst their way through one's chest.

The first *rencontre* with the gorillas took place on the afternoon of a day when I had indulged in the fatuous task of gorilla locating, toiling wearily up hill and down dale for several exhausting hours—in the wrong direction. Having reached the furthest point that we were likely to get that day, news was shouted down the valley from a
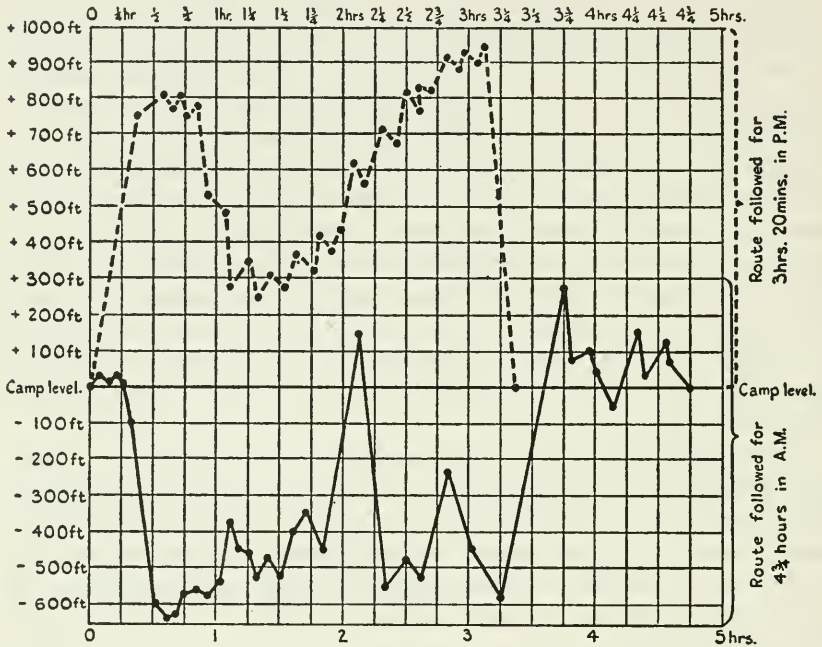

FIGURE 2.—Graphs, in terms of ascents and descents to the approximate time factor, of two routes followed during the same day in the course of gorilla investigations, in order to illustrate the existing conditions.

village many hundreds of feet above us, that gorillas had been located at no great distance the other side of the camp. So, before the quest could be really taken up there was first the exacting march back to headquarters; but see the graph (fig. 2)—most descriptive—of the day's wanderings. There is no need to describe the ups and downs, nor the type of country traversed, but what is noteworthy is the fact that the troop of five, which I was fortunate enough to be able to study at close quarters, was feeding in a forested valley less than a mile away from, and overlooked by, a small mountain settlement.

Most troops are easily located, as the guttural grunts with which at times the members appear to maintain a regular conversation can be heard at a considerable distance, and, in consequence, the pygmy

locators, by following the tops of the ridges, are likely at once to be aware of any that are about. In this case, shortly after the native huts had been left behind and the valley entered the gorillas were heard on the far side. It did not take long to reach the forest and scrub-covered slope where they were feeding.

It was then that I had a real surprise. Creeping forward as silently as possible, in the wake of my noiseless nimble guides until the grunts sounded alarmingly close, and agitated bushes and vegetation could be observed just below us, the leader of the file with a beaming face pointed cautiously, not at the cover below, but up into a tree almost above our party. And there was the old male, silverbacked and magnificent, 30 feet up a tree growing on the steeply sloping hillside; the other four, females and juveniles, all fairly large, were in the bushes below.

The Wambutte guides fearlessly crept to within 10 paces of the tree—our approach, of course, was screened from view—and the old male at once noticed us and scrutinized us keenly, but went on feeding. He turned to look at us again, had a few more mouthfuls of leaves, and then descending about 6 feet, sat down in a huge upright fork where the trunk divided, legs dangling, the excessively long arms grasping nearby branches, an interested, though kindly expression on his face, the enormous head framed in a thick fringe of long shaggy hair.

It is impossible to describe adequately what one felt at that supreme moment. There before one was something entirely unrecorded and new in connection with the world's largest and most interesting anthropoid, and what a giant he looked spread-eagled on a slanting branch to reach a particularly desirable mouthful. He was so large that at first I could not believe it was one animal, and thought it must be two.

Having looked our fill at each other, the Wambutte suggested that if we had seen enough we had better withdraw, and so we parted amicably. There had been no undue disturbance, and unconcernedly the gorillas continued to feed where they had been found, and even after we had emerged from the forest on the opposite hillside, their contented grunts could still be heard below. This guttural conversation, carried on so it appears by a succession of grunts differing in length and varying in key, can be heard at a distance, and, as previously mentioned, renders the location of a troop a comparatively simple matter.

When I set out to view this troop, which had been originally located by a villager from a nearby settlement, I was accompanied by six Wambutte, two villagers, and three members of my own staff. After I had seen all I wanted and was about to retrace my

steps, I found at least 50 unauthorized spearmen hanging in the rear hoping for the opportunity of attacking the gorillas. In fact, I was warned that if I did not personally see this crowd out of the locality, the moment my back was turned they intended going in to spear the male before he could get away from the tree, after which the slaughter of the other four would have been simple. Knowing full well that unauthorized they dare not attempt aggression, they were quite ready to take advantage of the presence of a European, afterwards making a misunderstanding their excuse. It shows how easily an unfortunate episode may develop unless all participants in gorilla investigations are authorized and absolutely under control.

The second meeting was more carefully planned (in March 1934), and the Wambutte, who had been instructed to locate gorillas and then keep in touch with them, were successful on the first day in finding a troop many miles to the north, and for the next 9 days were in contact with this and other bands, so that when the Governor arrived, it was possible the following morning to take him to a troop of eight within 1½ hours' march of camp.

Nearly 2½ hours were spent in the proximity of this lot, but owing to the excessive density and height of the undergrowth, in spite of the general conditions being exceptionally favorable, practically no opportunity was afforded of taking a photograph. This was not due to the gorillas having been disturbed, as, until the last half hour they were unaware of our presence, but just on account of the nature of the vegetation. Although, while under observation, they did not move out of an area of a few hundred yards square, one always seemed to be 5 minutes behind them. Vantage points used overlooked clearly patches of flattened undergrowth which would have provided marvelous photographic subjects if only the gorilla depredator could have been caught in the act.

But there is another side to the story when one is lamenting what "might have been." When there are eight unsuspecting gorillas feeding contentedly extremely near at hand, and when the precise location of never more than four of five is known at one and the same time, it behooves one to move forward very cannily, for if perchance one surprised a lagging female, her cry of alarm would in all probability provoke the male to more than wrath.

On this occasion it was lucky that it was possible always to keep above the feeding troop, which obviated considerably the possibility of serious danger. At one place the party stood on a broad platform overlooking the main valley: immediately below was a small feeder. It was a perfect setting for a picture—the vegetation-choked valley, a magnificent bank of tree-ferns growing on the abrupt opposite side, havoc just below the platform where the gorillas had fed a

few minutes previously—if only they would come out again—and, about 60 paces distant, violently agitated bushes and cover, with an occasional glimpse of a black shaggy body or a long hairy arm. Once there was a good view of a female as she swung down from a small tree beside a large bush. Dropping lightly to the ground, she offered a perfect facing view, one long arm momentarily upright grasping a stout branch. Others were seen at various times high up the smaller trees; in this respect my very limited experience suggests that the big male is more enterprising than his wives and children.

After the troop had become aware of our presence, and when it seemed quite hopeless to expect a chance to secure a photograph, the party retraced its steps up the hill, making a slight detour to follow a shoulder instead of forcing its way through a tangled reentrant. To our amazement the gorilla females and youngsters were observed a little below and parallel to our line of direction inquisitively creeping up the reentrant, and having a good stare at us by parting the undergrowth and peeping through as opportunity offered.

This boldness revived the idea of a photograph, but it was no good, the gorillas knew all about us and had no intention of exposing themselves unduly, and as soon as we began to descend again they vanished like a party of ghosts and were heard and seen no more. The most satisfactory feature of the whole episode is the fact that the gorillas were not unduly disturbed, and just faded away quietly. The preference for feeding in the vicinity of the valley bottoms is explained by the occurrence of more luxuriant vegetation induced by additional humidity.

The wrathful roar, sometimes aptly described as a hellish challenge, of the angered male is evidently a rarity in the Kayonsa region. In 18 months my prospector informant had never heard it, and the local natives—usually loquacious on such matters—did not appear to be impressed by any outstanding yell.

There are many gorilla noises, the one most frequently described by writers being the peculiar drumming of the chest. It is most certainly done as a challenge and not necessarily to frighten, and is by no means confined to demonstrating males, as is often claimed. It is a sound which carries a long distance, especially across a valley. The young males practice it at an early age, and Mok, directly after his arrival at Regent's Park, used to jump up suddenly from whatever he was doing and rush wildly round his cage bellowing and frantically beating his chest. The partially cupped hands, and the way in which they are held and strike the chest, are responsible for the penetrating nature of the sound.

The second meeting provided an entirely new noise—as far as I am aware there is no published description[4]—a curiously metallic bubbling note. It was much too even and fast for any breast-beating, and rippled forth as if made by rapidly closing and parting the lips. It must have been a signal, presumably uttered by the big male, probably a warning, as at that time the gorillas may have got the wind of our party. But beyond that sudden clear-cut ripple there was nothing to suggest that the gorillas were particularly on the qui vive, except possibly the care they took to keep well hidden, until more than half an hour later when one member of our party lit a cigarette, and a wisp of blue smoke drifted toward the concealed troop. Within a few moments there was a raucous bark from the male, and there was menace in its tone.

After that at 10-minute intervals until we decided to withdraw this bark was uttered. The situation was none too happy for the writer, who was acting as the protective unit—for a game warden it was an unenviable position. On the one hand, the sacred person of the governor, on the other the almost sacred and strictly protected gorilla. If the old male got really crusty, how close dare he be allowed to come, to make certain that he was only demonstrating? A radius of 10 paces was visualized, so near and no nearer, and just to cheer matters up the private secretary from time to time with a garrotting clutch at my throat hissed in my ear—"You must not shoot until the hand is out to grasp!" It was an awkward, tense period waiting for the unknown to happen, and if it did uncertain how to tackle it. As matters were, I do not suppose there was the least danger, but while patiently waiting there was plenty of time to think.

The Wambutte and Bachiga have a rich fund of strange tales in regard to gorilla behavior with which they regale one from time to time. Among the most entertaining is the idea that a gorilla will play "possum" sometimes when it realizes it has been observed by an intruding human. It pretends to run away, staggers about, then falls down and covers itself with dead leaves and any handy rubbish, and lies quite still. The intruder, puzzled, goes

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[4] The appended extract from a letter written by Mr. F. S. Collier of the Nigeria Forest Service, in West Africa, is of particular interest:

"That also reminds me that one point interested me very much in a report of yours of gorillas which I read some months ago but which I haven't got by me at the moment. As far as I remember, you commented on a "metallic bubbling noise" made by gorillas. I have only been near them once, in the Cameroons—a big solitary male which I couldn't get up to, in very thick stuff. Several times he made a queer noise which commenced as a quiet bubbling and gradually increased in volume, varying as though with the intake and expulsion of breath, and culminating in two or three snarling belches of tremendous volume. The native hunter said it was the beast's stomach and I imagined the noise to be involuntary as he was apparently alone and apparently not aware of our presence, for he kept moving on quietly and sitting down for short spells, until we got fed up with the heavy rain which was falling and chucked it."—C. R. S. P.

forward to investigate thinking it dead, when up leaps the cunning beast and kills him.

Another pretty fable concerns the way in which an interested gorilla can be duped with a display of spear throwing. The local folk wishing to destroy a gorilla with little risk of danger to themselves get into touch with a gorilla troop without disturbing it. If they find the old male is interested in them they indulge in a game of throwing spears at each other, but before a spear is thrown some grass is very openly wrapped around the blade. The one who returns the spear equally conspicuously does likewise. A spear with the blade partially wrapped is then hurled toward the gorilla, who entering into the game, recovers and returns it with an additional grass wrapping. The wrapping of grass is supposed to obviate the possibility of an accident. This to and fro play enables the human party to close gradually to within effective striking distance, when the blade is shorn of its protection and the missile hurled with deadly intent.

Still another relates to crop raiding, and it is said that the old male will remain behind and defy the puny humans who it evidently realizes are incapable (by law) of action which would seriously injure him. As the incensed natives try to drive him away, he raises himself upright and plucks handfuls of grass and vegetation which he brandishes high above his head. This, it is stated, he does to attract attention from the ground level to enable him to edge forward imperceptibly, and suddenly shoot out a leg and grasp an unsuspecting native. It is a pretty story, but unfortunately the creature's leg-length is very much shorter than that of an arm.

There are many others, but the above are some of the best samples.

During the journey back to camp after the second described successful day, many entertaining moving and still pictures were taken of the Wambutte by various members of the party. It was explained to the pygmies when the ciné cameras were prepared for action that movement was required and that they were to pretend to fight or something of the sort. So, absolutely on their own, they put up the most realistic imitation of a gorilla hunt, and the one who represented the gorilla played his part to perfection. It was a most amusing performance.

It has been previously stressed that the Kayonsa habitat nowhere attains a height of 8,000 feet. On the Birunga volcanoes one does not expect to see gorillas until the 10,000 level is reached. Nor are the gorillas of the volcanoes in the habit of ascending trees, and their beds are placed almost invariably on the ground.

The gorillas do not constitute the only subject of outstanding interest in this exceptionally attractive region, for locally the chimpanzee is plentiful, but it is a great wanderer and never seems to stay long in one place. Also, as a rule, the chimpanzee appears to avoid the favored haunts of its huge relative, and with one exception, in the neigh-

borhood of Mpororo, where a solitary bed was noted in a tree, their easily recognized sleeping quarters were not seen in the localities where the gorillas were accustomed to roam.

One afternoon I had a grand view of a band of about a dozen chimpanzees which had decided to spend the night in a little reentrant valley on the opposite hillside, and several hundred feet below my tent. With the aid of a pair of powerful binoculars I was able for several hours, till darkness put an end to the entertainment, to watch closely what they were doing when absolutely at their ease and never a suspicion of the watcher above. What struck me most was the extraordinarily human way in which these apes moved about the tree tops. When alarmed, or when speedy progress is desired, the chimpanzee uses primarily its long arms. But when feeding unconcernedly aloft and wishing to go down the nearest way to another branch it was most illuminating to see the care with which the descent was made. Grasping securely with both hands the branch it intended leaving, the chimpanzee slowly lowered itself till a foot reached the new stance, which was tested thoroughly, then followed the other foot, and the same performance repeated, after which, if satisfied, the ape let go its hands and, well-balanced, very cautiously lowered its body till the hands could grasp fresh security. Another point that was particularly striking was the fact that normally one arm always hung on tightly to an overhead branch, suggesting that the chimpanzee is not really at home in the trees, for those under observation did exhibit the most extraordinary care in their movements and an almost ludicrous solicitude for their own safety.

It was rarely possible at any one time to obtain a clear view of more than two or three individuals, but numerous, stationary, long, hairy arms, hanging on like grim death to the branches, indicated the whereabouts of most other members of the troop. For minutes on end, 12 minutes was the longest period timed, these arms stretched upward absolutely motionless. An adult male who desired to move from one treetop to the next was most comic. First of all he crawled out along an upward slanting branch which was really stout, and provided a ready highway to an equally thick branch of the other tree. But halfway his nerve failed him and he spread-eagled himself over the branch and thoroughly tested the whole structure with his hands and feet. Then, after several half-hearted attempts—there must have been something very tempting on the other tree—he plucked up courage and cautiously raising himself half upright pushed himself forward in a regular "belly-flop", and landed on his face and chest amidst the branches of his goal.

Just before dusk the whole troop busied itself building beds in three adjoining bushy-topped trees. These operations being mainly inside the canopy of the trees and the light failing it was impossible

to observe in detail the procedure. It is, however, noteworthy that the chimpanzees had arrived in that particular group of trees on the forested hill side about 2 p. m., and never moved out of them till after 8.30 the next morning.

The weird community howling indulged in almost immediately they had arrived, and kept up at varying intervals until the troop left next day, and even then heard intermittently for some time far away in a distant valley, is indescribable. Grunts, croaks, groans, barks, yells, piteous wails, unearthly shrieks, are a medley which tend to make the strangest discord one is ever likely to hear. The reason thereof is obscure, and why on earth when one starts the whole lot have to join in to produce the revolting chorus also requires explanation. Normally, chimpanzees are most vocal early and late, but this was an exceptionally noisy troop, either singing praises lustily to some particularly succulent food they had chanced upon, or simply letting off steam from pure *joie de vivre*. Whatever the cause, the effect was soul searing—and, if one had been close enough, earsplitting.

The howling was indulged in at about 20-minute intervals until just after 3:30, when it increased in frequency to once every 10 minutes. This was kept up till an hour after dark, until by 8:30 p. m. the discord had practically ceased. A bout shortly after midnight woke me up with a start, another outburst desecrated the early morn at 3:15, and then an hour before dawn till an hour and a half after the troop was once again really chatty. I can appreciate the necessity of the hideous riot occasionally in the night. The chimpanzees most certainly know it is voluminous, and, if frightened probably hope not only to terrify nocturnal prowlers, but also to comfort each other. Actually, I imagine, it serves to inform every prowler within earshot exactly where the troop is located.

One sometimes gets a parallel in the porters' camp when one is out in the blue. If the weather is fine, camp, of course, there is none, the porters sleeping in the open with guard fires around. A porter has a nightmare or gets a sudden fright, and utters a yell, and in a moment the whole lot are yelping loudly like a pack of hounds in full cry. No one attempts to move, they just lie and make as much racket as possible. It is immaterial whether elephant, rhinoceros, hippopotamus, buffalo, lion, or hyena are about, no one moves until the alarm has subsided. Then there is a buzz of conversation, followed by a roar of laughter, as the dreamer is discovered. Or, as once happened, a hyena had trodden on a sleeper, who had wakened to see a pair of glowing eyes almost touching his face—after that the excited chatter did not subside so easily. And I suspect it is the same with the chimpanzees. If one happens to yell in the night, whatever the

reason, all the others join in at once in sympathy. It is probably very comforting though not melodious.

A grotesque creature which occurs in abundance in the Kishasha Valley is the three-horned chameleon (*Chameleo j. johnstoni*). This oddity grows to a length exceeding 12 inches, and the males appear to retain some of the characters of the prehistoric type *Triceratops*, which they are not unlike in miniature, with three curious horns, 1 to 1½ inches in length, protruding forward from the nose and between the eyes. It is the male only which possesses this fearsome looking adornment, and the horns are used with extraordinary effect. The males are extremely pugnacious, and fight furiously, when the horns play the principal part, and these combats are worth watching. At times the contests develop into a tedious pushing match, when the horns are interlocked; at others a really vigorous fighter will dispose of its adversary in a few moments. The coloration of the males, chiefly brilliant blue, green and yellow, is particularly vivid and attractive. As is universal throughout Africa the local natives are terrified of chameleons.

Another interesting point about this region is the abundance of iron, in the form of powdery haematite about 90 percent pure. There are thousands of tons of it, and everywhere it can be found sticking above the surface. In this form it is comparatively simple for the local natives, with their primitive, though serviceable home-made bellows and forge to convert it into spear heads, bill hooks, and other necessary implements.

Unfortunately, I am not qualified to describe the beautiful flowers which grow in profusion in the valleys and on the more humid lower forest slopes. Wild balsams are amongst the commonest, and an unattractive white species, and another of Kaffir pink, abound everywhere. In the darker, damper localities is found a type, common in all the ultrawet forests of Uganda, with reddish stems and leaves, and deep red waxy flowers. A tiny species with minute white blooms is quite the most pleasing. Begonias, their floral artistry confined to shades of a combination of pink and white, are locally abundant. Some are small and grow in profusion pendant from the tree boughs, others of a climbing variety and very much larger attain an immense length. An unidentified flower with lovely mauve spikes grew in profuse masses in some moist places where more than the usual amount of sunlight penetrated. The strangest was a green, orchislike flower, the blossoms sparingly marked with delicate shades of brown and yellow.

On the open hill sides the *Erythrina* trees are found in flamboyant splendor, their marvellous scarlet flowers, which come out before the leaves, producing a wonderful effect against the dark background. The vivid coloration can be seen for miles with the naked eye. A

magnificent specimen, the largest seen, was at least 60 feet high and had a vast spread. Aflame with blossom, it was absolutely gorgeous. This tree called locally "ekirikiti" is an object of veneration. There are, of course, many others, but the above are those which either caught the eye or were most impressive.

Finally, it is hoped in the not distant future to make the further acquaintance of the Kayonsa gorilla, and, if possible, for a considerably longer period, so as to enable more comprehensive investigations to be made.

EXPLANATION OF PLATES

Plate 1

1. The uninviting mountain fastnesses (Mount Sabinio) of the Uganda mountain gorilla.
2. Morning panorama of six volcanoes in the Mufumbiro group. The boundary of mandated Ruanda, Belgian Congo, and Uganda, passes across the summits of Muhavura (approximately 13,500 feet), Mgahinga (approximately 11,500 feet), and Sabinio (approximately 12,000 feet). The others (Mikeno exceeds 14,500 feet) are in Belgian territory. The whole group, primarily the Belgian zone, is the home of the typical mountain gorilla.

   Reading from left to right the photograph includes Muhavura, Mgahinga, Sabinio, Vishoke in foreground with Karissimbi in the clouds, and Mikeno.

Plate 2

Kigezi scenery taken from the gorilla forest at Mpororo. Lake Mutanda in right center, Mount Mgahinga above it in right background, and Mount Muhavura on left.

Plate 3

1. Typical gorilla forest near Kasatora (the highest point just below 8,000 feet) in the Kayonsa region.
2. Wambutte pygmies on Niwashenya. Reproduced by permission of P. O. C. Ray.

Plate 4

1. Gorilla bed nearly 50 feet up in a fairly large tree. Used the previous night. (Reproduced by permission of His Excellency the Governor of Uganda, Sir B. H. Bourdillon, K. C. M. G., K. B. E.)
2. Gorilla bed 10 feet above the ground. One of a group of four. It was filthy and festooned with excreta.

Plate 5

1. Gorilla country west of Niwashenya.
2. An abrupt, dome-shaped, bracken-covered hill west of the Kishasha Valley and immediately above the locality where the first troop of gorillas was viewed.

Plate 6

Lofty tree-ferns almost obscured by tangled vegetation and matted creepers on the steep hill slope of Mpororo. In right foreground below the tree-fern is a large hole from which, a few days previously, a huge male gorilla had suddenly and silently emerged to confront two prospectors who were plodding up a mountain track.

PLATE 1
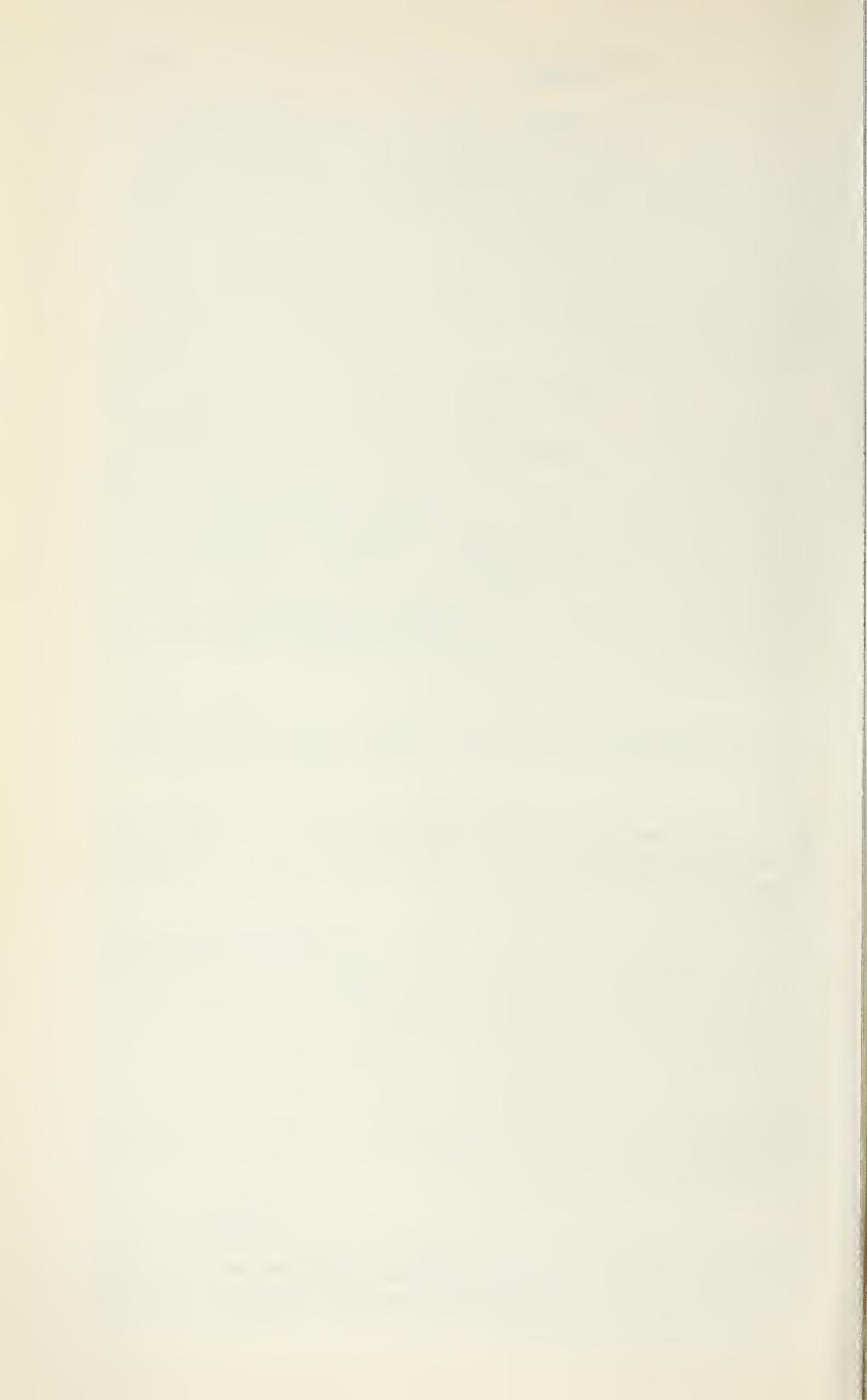
1. THE MOUNTAIN FASTNESSES OF THE UGANDA MOUNTAIN GORILLA.
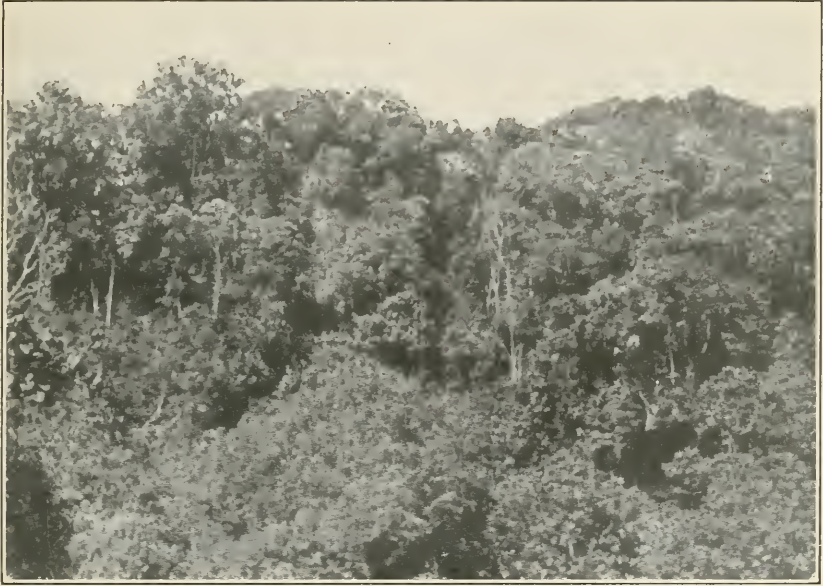

2. MORNING PANORAMA OF SIX VOLCANOES IN THE MUFUMBIRO GROUP

PLATE 2

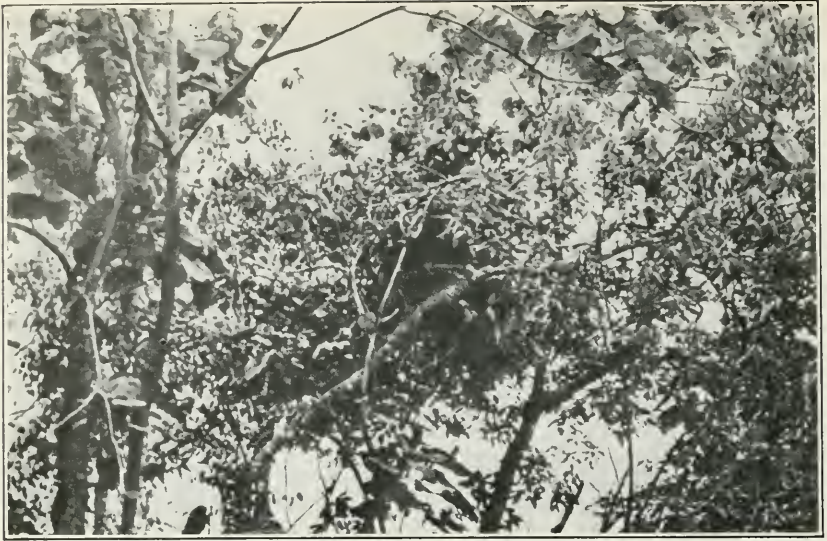Kigezi Scenery Taken From the Gorilla Forest at Mpororo.

1. TYPICAL GORILLA FOREST NEAR KASATORA.

2. WAMBUTTE PYGMIES ON NIWASHENYA.

1. Gorilla Bed 50 Feet Up in a Fairly Large Tree.

2. Gorilla Bed 10 Feet Above Ground.

1. GORILLA COUNTRY WEST OF NIWASHENYA.

2. ABRUPT, DOME-SHAPED HILL WEST OF KISHASHA VALLEY.

LOFTY TREE-FERNS ALMOST OBSCURED BY TANGLED VEGETATION ON THE STEEP
SLOPE OF MPORORO.

THE VAMPIRE BAT [1]

A PRESENTATION OF UNDESCRIBED HABITS AND REVIEW OF ITS HISTORY

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and

Arthur M. Greenhall

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[With 4 plates]

This article follows intensive studies of the vampire bat, *Desmodus rotundus*, during trips to Panama and Trinidad during 1933 and 1934, and observations of specimens in captivity from both areas. Between field reconnoiters, a thorough search of the literature has been made. The work has thus produced a quite complete history by bringing together recorded observations, references to studies of important pathogenic significance, and notes of studies made by the authors. Thus collectively clad, the vampire assumes a more interesting and specialized form than past description has accorded it.

The studies of *Desmodus* outlined here were suggested to the senior author in the summer of 1932 during a collecting trip in Central America. The trip was concluded with a call upon Dr. Herbert C. Clark, Director of the Gorgas Memorial Laboratory in Panama. Dr. Clark told about his work with Dr. Lawrence H. Dunn in proving the vampire bat to be the carrier of a trypanosome existing in the blood of cattle, to which cattle were resistant, but fatal to equines. As cattle ranged in large numbers with horses and mules at night, and bats indiscriminately attacked both, the working out of remedial measures was a highly important problem.[2]

Several vampires were under observation at the Memorial Laboratory. They had been maintained for a number of months on a diet of blood obtained at a nearby slaugterhouse and defibrinated to keep it in fluid condition. Here was a demonstration of the practicability of maintaining this highly interesting species as an exhibit

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at the Zoological Park. Dr. Clark, however, could spare none of his specimens. All were needed to demonstrate the susceptibility of the vampire itself after biting infected cattle or being injected with the organisms. It was there indicated, and since proved, by Clark and Dunn, that after biting infected cattle, the bat continues its blood feasts night after night, but itself succumbs in a period of about 30 days.

The senior author decided to return to Panama the following summer and search the caves where vampires had been captured. Hence in August of 1933, accompanied by Arthur M. Greenhall, then a student at the University of Michigan, Panama was again visited and Dr. Clark provided guides to explore the Chilibrillo Caves in the Chagres Valley. We were informed that the caves were of limestone formation, with horizontal tunnels. In some parts these gave way to large chambers, from which again other tunnels led into the mountain. We were equipped with headband lamps and batteries carried on our belts.

In a shack near the caves was an illustration of the frequency with which humans may be bitten by vampire bats. A boy about 10 years old had been bitten five times during a week, and always on the under surface of his toes while he slept. He had bled profusely, and the earthen floor beneath his slatted bed was blood-stained each morning.

The route to the caves led through cattle trails in low, green tangle, with ankle-deep mud most of the way, as the period was the rainy season. There was a steep slope near the caves and a growth of rain-forest. The Panaman guides, pushing through barricades of vines, disclosed a hole in the ground. It appeared to be little more than the entrance to a coal chute. We slid in and found ourselves in a horizontal tunnel in which we could walk upright in single file. The tunnel soon grew wider and higher, the floor slippery with red mud. Through portions of this entering gallery there was swiftly flowing water, knee deep in places. It appeared to come through the sides, then to seep through crevices in the floor. By pointing a light overhead, a double procession of big bats could be seen, the two streams flying in opposite directions.

After we had worked forward a fair fraction of a mile, the subterranean stream gave way again to the slippery floor. The hallway became larger and now showed side galleries. The guides stopped there to assemble the handles of the nets by which the bats were to be taken. The atmosphere was unlike that of caves in the temperate latitudes; the air was hot, heavy, and sweetish, the latter condition resulting from the odor of thousands of bats. Common on the limestone walls were huge roaches, of pale, straw color. Another insect

denizen, not apparent without search of nearby crevices, but possibly common enough, was a member of the hemiptera, of the genus *Triatoma*. This is a small, reddish, blood-sucking bug, coming under strong suspicion in recent studies of carrying the organism of Chagas fever, a disease produced by a trypanosome in human blood, diagnosed and discovered by Dr. Emilio Chagas. Here and there, in startling contrast on the walls, were spiderlike creatures with a spread of limbs of 5 inches or more. These arthropods appear to be cave-dwelling members of the *Thelyphonidae*, to which the whip scorpion belongs.

We finally entered a big chamber, the arched ceiling of which appeared to rise about 50 feet. The ceiling looked smooth, yet it was rough enough to provide a hanging foothold for thousands of bats of several kinds. Each species hung in a cluster of its own, the smaller, insectivorous kinds and smaller fruit bats on the sides. Near the dome of the ceiling was a mass of spear-nosed bats (*Phyllostomus*), in a cluster about 15 feet in diameter. These bats have a wing spread of about 20 inches and bodies the size of a rat. Our lights disturbed them and caused a great shuffling of wings and movement of innumerable faces. There was considerable chattering from these larger bats, and their teeth showed plainly.

The side galleries were also full of bats and we inspected these in search of the big carnivorous *Phyllostomus* which could not be captured in the high chamber. We caught 18 and "fought" them into a mesh cage. All the while we were watching for vampires, which may be distinguished by their habit of running along the vertical walls and darting into crevices to hide. In a deep side gallery we found bats of a kind not noted in the large chamber, but again no vampires. After several hours we retraced our way along the subterranean stream until, with a feeling of relief from the oppressive atmosphere, we saw a faint glow that showed we were close to the entrance of the cave.

After a breathing spell we sought and found the entrance to another cave shown on our chart. The route sloped easily toward a circular chamber fully 100 feet in diameter, though not more than 8 feet high. Here were hundreds of bats hanging in clusters, and all of one kind—a medium-sized spear-nosed bat of a fruit-eating species. They were not timid and could be closely approached before they took flight. When a hand was waved close to them the result was a pouring of winged bodies from the ceiling until the air was filled. Again we made an unsuccessful search of the walls for vampires.

The third cavern had an almost vertical entrance through a well-like shaft. There was not room enough to get down with the nets. We lowered ourselves into the hole, reached a horizontal turn-off, and

on flashing our lamps against the wall, saw several bats run like rodents along the vertical surface, then dart into crevices. We immediately identified them as vampires, but all escaped.

With lights turned out we waited a half hour, but the bats did not reappear. We explored another gallery and found a spot where a slender man might squeeze through. We were too fatigued to continue, however.

The only other passage sheered off at a ledge beneath which ran a channel of water, from wall to wall, which looked as if it were quite deep. There the day's reconnoiter ended.

The following morning we returned to the cave where the vampires had been seen and with much caution descended to the widened area, keeping the lights out and feeling our way. Ready with some small nets we had prepared the previous evening, we flashed the lights on the wall where the bats had been seen, but no vampires were anywhere in sight.

We reasoned that the vampires had retreated into the recesses of the tunnel with the deep water, or into the narrow shaft where only a slender man could get through. Greenhall worked into this small, horizontal shaft and saw several vampires in a widened space ahead. He captured two and the others made their way into the tunnel with the deep water, which connected with a passage ahead.

Of the two vampires captured, one soon died. It was half grown and possibly had been injured in the net. The other, an adult female, lived for approximately 4 months after capture and, slightly more than 3 months after being caught, gave birth to a single vigorous infant. While as yet we do not know the period of gestation, the length of time from capture of the mother to birth of the young shows a surprisingly long period of pregnancy for such a small mammal.

After obtaining the female vampire, we left for the Atlantic side of the Canal Zone. Dr. Clark provided two quarts of defibrinated blood, fresh from the automatic refrigerator of his laboratory, but from that moment until we reached New York the vampire was a problem. We were naturally very keen to get it back alive. We were not worried about the 18 big carnivorous bats; they were feeding ravenously and fresh meat could be readily obtained. With an assortment of crates containing reptiles and amphibians, and cases of preserved specimens for the museums, we boarded a train for Colon. The defibrinated blood was in a package beside us, and the cage containing the vampire was swathed in black cloth. Dr. Clark had cautioned us to get the blood on ice again as soon as possible.

On the Atlantic side it was necessary for the senior author to stop 2 days at the Navy Submarine Base at Coco Solo to deliver several lectures. The commanding officer invited us to stay at his residence

and here the defibrinated blood was placed on ice, while the bat was domiciled in the garage. That night some of the blood was measured out in a flat dish. The amount would have filled a fair-sized wineglass. The bat hung head downward from the top of its cage when the dish was placed inside and would not come down to drink while we were there. Early the next morning we inspected the cage and found the dish nearly empty.

That routine never varied during the 10 days' voyage to New York, with stops at Colombian ports. We never saw the bat drink the blood, but in the quiet of the night she took her meal. At the Park the senior author decided to keep the vampire in the reptile house where the temperature was automatically maintained and the atmosphere was damp, like a greenhouse. In roomy quarters she quickly settled down. Blood was defibrinated in the Park's research laboratory and the dish was never placed in the cage until dark. For several weeks, however, despite cautious inspections with a flashlight, no observations of her visits to the dish could be made, although at some time during the night the blood was consumed.

At last the vampire became tame enough to show a lively interest when the dish was placed in the cage. She would crawl down the mesh side a few steps, peer at the dish, then creep back to her favorite nook in a corner, where she would hang head downward, by one leg. Each night she came further down and wandered along the sides of the cage before retreating. Her deliberate motions were surprising: A slow stalk, head downward, and a retreat equally deliberate. Her subsequent actions added much to information gleaned from the history of the species.

When the blood had been set in the cage, the observer took his stand in what developed into a series of nightly vigils. Finally there came a night when the bat descended the side of the cage with her usual deliberation. Reaching the bottom, she started across the floor with wings so compactly held that they looked like slender forelimbs of a 4-footed animal. Her rear limbs were directed downward. In this way her body was reared a full two inches from the floor. She looked like a big spider and her slow gait increased that effect. Her long thumbs were directed forward and outward, serving as feet. Anyone not knowing what she was would have been unlikely to suspect her of being a bat. In this trip to the dish it appeared that an unpublished habit of the vampire had been observed, and this, possibly, was the method the bat used for prowling over a sleeping victim in seeking a spot to use the highly perfected teeth in starting a flow of blood.

But other revelations were in store. Bending over the dish, the bat darted her tongue into the sanguineous meal. Her lips were never near the blood. The tongue was relatively long. It moved

at the rate of about four darts a second. At the instant of protrusion it was pinkish, but once in action it functioned so perfectly that a pulsating ribbon of blood spanned the gap between the surface of the fluid and the creature's lips. In 20 minutes nothing remained but a red ring at the bottom of the dish. The bat's body was so distended that it appeared spherical. She backed off from the dish, appeared to squat, then leap, and her wings spread like a flash. She left the floor and in a flying movement too quick for the eye to follow hooked a hind claw overhead and hung, head down, in her usual position of rest. Gorged and inverted, she preened herself like a cat, stopping occasionally to peer out of the cage in the light of the single, shielded lamp to which she had become accustomed.

Summarized, these observations appear to add much to the history of *Desmodus*. In less than half an hour it had been demonstrated that the vampire can assume a walking gait as agile as a 4-legged animal; that the reason for its long thumb is its use as a foot on the wing stalk; that it is not a blood-sucking creature as has long been alleged; that it can gorge itself prodigiously and assume an inverted position to digest its meal.

The problem of recording these actions on motion picture film was at once considered. The outlook was doubtful. If the vampire had been hesitant about performing up to that evening in the illumination of a single, shielded light, it appeared that lights of enough actinic power for photography, yet tolerable upon the bat, would necessitate a slow introduction and increasing the strength of the lamps. The observer's plan was to build up the illumination, night after night, through a resistance coil, or dimmer.

Two weeks were spent in gradually increasing the strength of the light. Ultimately the bat tolerated three 500 watt bulbs, with a reflector. The scenes were exposed on 35 mm pancromatic film. The lens employed was a 4-inch Zeiss, with long light-cone. Results were clear and satisfactory and the greater number of the illustrations accompanying this article are enlargements from the motion-picture scenes.

Since contentions as to new habits, based upon a single specimen, are far more satisfactory if they are afterward substantiated by observations of additional individuals, it was determined that field observations should be continued and additional vampires obtained during the summer of 1934. Meanwhile the junior author started a search of the literature for observations other than the mere statement that the vampire is a blood-sucking animal. This search, conducted in the library of the University of Michigan, revealed an interesting continuity of inferences concerning habits, and some authentic observations.

Beginning with the earliest descriptions of the habits of the vampire bat, allegations point to a blood-sucking creature. This is seen in the writings of Aldrovandi, Shaw, Cuvier, Buffon, Geoffroy St. Hilaire, Swainson, Gervais, Hensel, Goeldi, Quelch, and others. Recent writers such as Gadow (1908), Dugés (1911), and Herera (1911) have indicated that the vampire applies its lips to the wound made by specialized teeth, in order to pick up the ensuing flow of blood.

Charles Darwin appears to have been the first scientist to observe a vampire in the act of drawing blood and note its procedure with satisfactory clarity. He secured a bat and definitely recorded the sanguineous habits of *Desmodus*. Previous to this, several larger species of bats had been under suspicion. Darwin's (1890) observation, however, did not change the belief that *Desmodus* was a blood-sucking type. Nor could anything to the contrary be found in comparatively recent writing until the publication of an article by Dr. Dunn (1932) containing the following:

> The vampire does not suck blood, as popularly believed, but takes it up with its tongue, seldom placing its mouth on the wound except when the latter is first made or when the bleeding is very slow. If the wound bleeds freely, the bat simply laps up the blood, hardly touching the tissues, while if the bleeding is scant the bat licks the wound.

Thus Dunn's observation, but a few years past, takes precedence, as far as could be found, in rectifying a long procession of erroneous inferences about the feeding habits of the vampire.

In further elucidation is a letter from Dr. Clark, dated April 18, 1934, and reading in part:

> Our vampire does not suck the blood. It uses its tongue to collect the blood, in a back and forth motion, rather than as a dog or cat laps up water and milk. I have seen them feed from the edge of cuts on horses, but, of course, never got close enough under these conditions to see the tongue in action. Animal feedings offered the bats under laboratory conditions establish the fact that they lick the blood.

As to the quadrupedal gait of the vampire, apparently the first mention of it is in the works of the Rev. J. G. Wood (1869), who states that vampires can walk, rather than grovel like other bats, but the description is insufficient in indicating the habit.

Dr. William Beebe (1925), in his book outlining experiences in British Guiana, states:

> We ascertained, however, that there was no truth in the belief that they (vampires) hovered or kept fanning with their wings * * *. Now and then a small body touched the sheet for an instant, then, with a soft little tap, a vampire alighted on my chest.
>
> Slowly it crept forward, but I hardly felt the pushing of the feet and pulling of the thumbs as it crawled along. If I had been asleep, I should not have awakened.

Dr. Beebe's observation, though made in the dark, is good substantiation of the senior author's surmise about the soft gait of the bat in reconnoitering its prey. Dr. Beebe's description of the pushing of the feet and pulling with the thumbs does not however, define the actual action of the vampire, which walks, with body well elevated from the ground and the elongated thumbs used as feet.

In further substantiation of the observation that the bat has a walking gait, the senior author was informed by Sacha Siemel, an explorer of the Brazilian jungle, that while he was conducting a party close to the Bolivian frontier, a number of vampires attacked the horses. Mr. Siemel, with a flashlight, carefully noted the actions of the bats. Some he saw lapping blood from fresh wounds, while others, as yet undecided upon areas to bite, stalked back and forth over the animals' backs, walked among the matted leaves of the forest floor, or hopped from one spot to another.

OBSERVATIONS DURING 1934

For the tropical reconnoiter of this year, the senior author planned a trip along the entire chain of the West Indies, terminating at its southerly end in collecting work in Trinidad and British Guiana. The junior author left a month ahead, on July 19, bearing a letter which put him in contact in Trinidad with Prof. F. W. Urich of the Imperial College of Tropical Agriculture. Professor Urich he found engaged in an investigation, operating on a government grant, of the transmission of paralytic rabies by vampire bats. The disease was seriously prevalent among cattle and thus far fatal, although vaccine is now being administered to immunize the herds. The disease was also fatal to about 35 humans over a period of years. They were dwellers in the back areas where vampires are commonest, and the bat is not known to attack humans in the cities and towns.

Professor Urich and his field assistant, J. P. L. Wehekind, extended much aid in getting together a collection of various specimens for the Zoological Park and providing transportation to different parts of the island. Several days after arrival in Trinidad the junior author, accompanied by William Bridges, captured seven vampire bats in the Diego Martin Cave.[3]

The newly captured bats were taken to the Government stock farm and placed in a small framework building with sides of wire screen. In this building was another vampire that had been under the observation of Professor Urich for about 3 months. He had studied its feeding habits on goats and fowls. This bat was tame enough

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[3] For details of a month's collecting work in Trinidad and Demarara, note serial account by William Bridges, N. Y. Sun, July 30 to Sept. 12, 1934.

to come down and feed while observers stood quietly in the room. Notes made by Professor Urich during the studies by himself and his field assistant appeared in the monthly reports of the Board of Agriculture of Trinidad and Tobago. From these, Professor Urich granted permission to quote as follows:

May report. (Observation on May 19, 1934.) When I got there at 9:40 p. m., found the bat feeding on the left foot of the cock, about 1 inch below the spur. The bat does not suck the blood, but laps it. Bat fed for 12 minutes from the time I arrived, the cock standing absolutely still. Then the cock started to walk, the bat following along the ground, and fed again. The cock became restless and walked away. Then it went into a corner of the cage, on the ground. [Observation by Wehekind.]

June report. (Observation on June 27, 1934). Bat started feeding at 8:30 p. m. and finished at 8:40 p. m., being so gorged that he could scarely fly. Bat dropped straight on goat and started to feed. No hovering. [Observation by Wehekind.]

In a later report.

As the *Desmodus* fed readily in captivity on fowls or goats, Mr. Wehekind was able to ascertain the method of feeding of these bats on fowls. It is quite different as stated in some records, the principal features of which are that the bat does not hover around its victims, does not suck blood, and does a fair amount of walking around on the victim to secure a suitable place for feeding. This is carried out by making a narrow groove in the place selected and lapping up the blood as it exudes from the wound. The bat always returns to an old wound on the same animal on its daily feeding. All these observations were verified by me (F. W. Urich) on several occasions.

The junior author of the present review adds the following notes from observations made in the screened house where the bats were quartered:

On Friday, August 3, 1934, at 6 p. m., Prof. F. W. Urich and myself went to the Government stock farm to see the condition of the captive vampire bats. One male vampire has been under Professor Urich's observation since May 18. It is known as "Tommy." When we caught seven additional vampires, Tommy was placed in a cage by himself, as it was known that he was free from paralytic rabies. Professor Urich then attempted to feed Tommy with defibrinated blood. The bat was used to feeding upon goats and fowls that were introduced into the cage and evidently did not relish the diet of prepared blood in a small dish. It seems to have taken a small quantity, but we thought it best to release it with the others after the necessary quarantine.

At the time we entered the bat cage we found that a goat had been placed inside for the other vampires to feed on. The goat had been freshly bitten, as I noted three open wounds, two on the left side of the neck and one on the right, from which blood was oozing.

The goat was calm, standing in one corner and no bats were feeding when we entered. Tommy was released from his quarantine quarters, flew and attached himself by the hind foot on the screening of the house, about a foot and a half from the sill. The goat was standing not far away from the vampire. The bat remained hanging for about 5 minutes, the thumbs bracing the body, the wings folded close to the arms. After a short interval, the bat

showed signs of movement. The head nodded; the lips were drawn back, exposing the large canines and protruding incisor teeth. The bat's gaze finally rested upon the goat. I was watching approximately 4 feet away from the bat and the goat was nearer to me. Slowly the bat moved down the screen, a deliberate stalk. The fore and hind feet were lifted high from the wiring and the body was well above the mesh. The bat stalked down and I noticed that the movement of the forearm in the stride was exceptionally slow, the wings folded tightly. From 2 to 3 minutes were required to traverse the distance from the original position to the sill. Upon arriving at the edge of the sill, the vampire hung from its hind feet and dangled over the edge into space. There, it remained for about 2 more minutes. The goat was still standing in the same position. Suddenly and silently the vampire launched itself into the air and lightly landed on the middle portion of the goat's back. There was still no movement on the part of the goat. I moved quietly forward until I was but 2 feet from the goat. Tommy stalked to the shoulder and neck regions of the animal. After a minute or so of searching, the bat buried its head close to the skin of the goat. There were a few up and down motions of the bat's head.[4] The goat then took a few steps forward and turned its head to the right and left. The bat drew itself up but continued the nodding motions. The goat walked around the room rather rapidly, the vampire hanging on and thus riding its host. The goat passed by me, then stopped, and I noticed that blood was exuding from a small wound and the bat was lapping it with a rapid darting of the tongue. The goat started to walk again and passed under a sort of table, a board of which brushed heavily against the animal's back. The goat was, in fact, obliged to slightly lower itself to pass under. The vampire quickly scuttled down the shoulder of the goat to avoid being brushed off. When the goat cleared the table the bat as quickly returned to the wound and continued lapping. We then forced the goat to go back under the table several times, the bat dextrously avoiding being hit by dodging down the shoulder. The movement was very agile and reminded me somewhat of the behavior of a crab. The bat could move both forward, backward, and sideways, but seemingly preferred head first.

I then reached out my hand and succeeded in touching the vampire, which attempted to dodge. It did not, however, make any movement to fly. The goat by now was exceptionally restless and ran back and forth around the room. It was a timid animal and it was of us that it was afraid. When we left, the bat was still riding the goat.

Later visits to the enclosure showed some of the other bats flying down from the ceiling, landing on "all fours" upon the floor, then hopping like toads from one spot to another, instead of assuming the walking gait. On one occasion a bat was seen to be so gorged and heavy from its sanguineous meal that it slid off the back of a goat to the floor. It was unable to launch itself in flight from the floor, hence climbed the wall, with head inverted, and when midway up launched itself in flight, returning to its customary hanging place on a ceiling beam.

When the senior author arrived in Trinidad, he spent considerable time observing the bats during the early evening, in the screened

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[4] The act of pushing aside the pelage and of biting.

room. His notes on feeding actions would be nothing more than repetition of what has already been brought out. What he noted particularly was the general tolerance of the goat to bats which crawled over its back or even wandered up the neck to the head. For a time after alighting on a goat, the vampire was not inclined to bite, but rested on the dorsal area, a bit forward of the shoulder, or clung to the side, where it looked like a big spider. This latter position is shown among the plates accompanying this article. The wandering of the bat upon the strangely tolerant host, the occasional lifting of the bat's head, the leer that disclosed its keen teeth, and the observer's realization that all of this pointed to a sanguineous meal, produced a sinister and impressive effect.

When the wound had been made, the tongue of the bat seemed to move slower than when lapping blood from a dish, and was extended far enough to come well in contact with the tissue. Goats of the laboratory herd, which had been previously bitten while heavily haired, showed bare spots surrounding the area of former wounds. The wounds themselves had healed as a slightly indicated ridge, from three-sixteenths to a quarter of an inch in length, but the area devoid of hair was as large as, or larger than, one's thumbnail. Apparently the hair had been shed in the area of the wound. Here may be a condition of "desensitization" in a vampire bite, with attending destruction of hair follicles. It has been suggested, though not with satisfactory evidence, that the saliva of the bat contains an anticoagulent, which might account for many bites bleeding for several hours. The term "desensitization", as here used, may be rather a loose one, but it signifies that something abnormal has happened to the tissue besides the opening of a mere wound by specialized and lancing incisor teeth. There can certainly be no injection of an anticoagulant, but there is a possibility of the application of some salivary secretion during the action of the bat's lapping tongue—a secretion retarding the formation of a clot about the wound. This matter will be considered in a treatment of physiological characteristics in following paragraphs relating to investigations now under way with four vampires, in the possession of the senior author.

Field observations in Trinidad indicated vampire bats to be fairly common, but not generally distributed. Near the base of the Aripo heights, particularly, frequent bites were reported. The bats attacked cattle, swine, and poultry. Sows were bitten upon the teats and the wounds in healing so shriveled these members that the animals were unable to nurse their young. Most fowls were unable to survive the loss of blood and were found dead in the morning.

Around a dish of defibrinated blood, the feeding motions of the four vampires brought back from Trinidad duplicated the notes made

upon the Panama specimen of the preceding year, though the latter represented a different subspecies. The animals so gorge themselves that their bodies become almost spherical. This gorging consumes from 20 to 25 minutes.

In some experiments with large fowls, weighing up to 8 pounds, the bats were observed to be extremely cautious in their approach, slowly stalking in a circle wide enough to keep out of reach of the bird's bill. An action of that kind might readily kill a light-bodied bat. After several circular maneuvers, an approach was made to the fowl's feet, the bat feeling its way forward inch by inch, and finally nibbling gently at the under surface of the toe. This appeared to serve the purpose of getting the fowl accustomed to its toe being touched. If the fowl made an abrupt move, the bat would dart backward, then slowly stalk forward to resume its attack. Whether any slight "shaving" of the tissue was taking place and a salivary secretion was being applied by the tongue it was impossible to determine, as the bats were too timid to bear extremely close inspection. After these preliminaries, however, the mouth was rather slowly opened as if to gage precisely the sweep of the incisor teeth, and then there was a quick and positive bite. While it has been customary to allege the utter painlessness of vampire bites, in several instances where fowls were under observation, there was a decided reaction of motion on the birds' part, showing that the bite was sharply felt. If the fowl moved, the bat darted back, but immediately returned to the wound, now freely bleeding. From this point the bat continued its meal and the fowl paid no further attention to it.

PHYSIOLOGY

Desmodus is no larger than the larger insectivorous bats. A particularly good female example of *D. rotundus rotundus*, from Brazil, shows a length of body of 4 inches and a wing spread of 13 inches.

The incisor teeth are extremely sharp and have a curvature that forms a scooplike mechanism. The incisors are well in advance of the canines. The lower incisors are widely separated, forming a partial channel for the darting motion of the tongue in taking up blood from a wound. Examination of bites shows a craterlike wound. The sharp upper canines, being set far behind the incisors, appear to play little part in most wounds.

Experiences of reliable observers point to a remarkable painlessness of the average vampire bite. There are statements that victims knew nothing of the attack, and would have remained ignorant of such a happening had they not found blood stains the following morning. An expedition from the University of Michigan in Santa Marta, Colombia, may be cited (Ruthven, 1922) :

We did sleep, but so soundly that it was not until morning that we discovered that we had been raided during the night by vampire bats, and the whole party was covered with blood stains from the many bites of these bats. It may seem unreasonable to the uninitiated that we could have been thus bitten and not be disturbed in our sleep, but the fact is that there is no pain produced at the time of the bite, nor indeed for some hours afterward.

In a previous paragraph it has been noted that a fowl, introduced into a cage with vampires, flinched upon being bitten, this observation being made by the senior author. Examining some of the recent studies of Dunn, it appears that the younger bats are not so expert in effecting their bites and that experimenters testing the bites of various specimens upon the human forearm occasionally found bats that dealt decidedly painful bites.

There is controversy as to whether the bat carries an anticoagulant in its saliva, introducing it into the freshly-made wound to keep it bleeding, or whether a specialized type of bite induces prolonged bleeding. Bier (1932), of the Biological Society of São Paulo, Brazil, experimented with extracts of the salivary glands of *Desmodus* and also with a species of *Phyllostomus* (*P. hastatus*). His published results indicate that *Desmodus* possessed anticoagulating properties in its saliva, while the nonhematophagus bat's saliva was completely inactive. In October 1934 Dr. Barry King, of Columbia University, began experiments with the four vampire bats now in the care of the senior author. This work points to an anticoagulant in the salivary secretion of *Desmodus*, but time and checking will be required to define its activity.

Although mosquitoes, blood-sucking flies, ticks, and lice have long been known to harbor disease organisms in their saliva, the vampire bat only recently came under suspicion. The work of Clark and Dunn at the Gorgas Memorial Laboratory has confirmed the guilt of the bat. These investigators demonstrated that *Desmodus rotundus murinus* is a vector of the equine disease murrina, prevalent in Panama and produced by *Trypanosoma hippicum* Darling. It is interesting to note that the disease also proved to be fatal to all of the bats carrying the trypanosome, although they live long enough after becoming infected to produce grave damage.

While there have been statements that vampires appeared to be unable to endure a fast of not much more than 36 hours, Urich states that vampires can fast as long as 3 days. The senior author fasted four specimens for 48 hours, seemingly without harm.

As early as 1865 Huxley made a detailed study of the stomach of *Desmodus* and found that its extremely intestiform shape was apparently specialized for rapid assimilation. This, together with the specialized dentition and peculiar type of quadrupedal gait, make the vampire especially adapted to its sanguinary mode of living.

TRADITION

The term "vampire" originated long before civilized man's knowledge of a so-called blood-sucking bat. In later years the discovery of a sanguineous bat appears to have inspired elaboration of the tradition. This history has been traced by the junior author through approximately 200 titles, a partial bibliography of which appears at the end of the article. Surmise, theories, and observations of various naturalists in building up the history of the vampire bat have also been searched, as well as scientific nomenclature.

The term "vampire" is apparently of Slavonic origin and was first applied in eastern Europe to alleged blood-sucking, supernatural beings and persons abnormally endowed with hematoposia. The preternatural vampire was supposed to be the soul of a dead person which left the interred body at night, in one of many forms, to suck the blood of sleeping persons and sometimes animals. Of the numerous shapes thought to be assumed by the vampire, it is of interest to note that in early history the bat form was not mentioned. It later found its way into the legends, as brought out in Bram Stoker's Dracula. The preferred form seems to have been the werewolf, dog, cat, horse, birds of various kinds, snakes, and even inanimate things such as straw and white flame.

Superstition about blood-sucking forms has been widespread and of dateless origin. It was known in many ancient cultures of the Old World. The tendency of blood-sucking creatures to produce legends is to be noted among the Mayans even before the arrival of Cortez in the early sixteenth century brought contact with Old World superstitions. In this case of New World exaggeration, there was a basis for it—the actual presence of sanguineous bats. Here was reverence of a blood-sucking bat god (MacCulloch, 1932), undoubtedly founded on the existence of a sanguineous bat common in most of the Mayan areas of habitation. Then again, the return of Cortez's followers to Europe with tales of blood-sucking bats, founded on acquired knowledge of an actual blood-drinking creature, appears to have strengthened the superstitions of Europe. From chronological examination of the old literature, it seems that it was not long after the return of the Spaniards that allegations appeared about blood-sucking habits of the bats of Europe, where no sanguivorous bats have ever occurred.

After the return of the early explorers from the New World tropics, a "vampire" epidemic broke out in Europe about 1730 (Encyclopaedia Britannica, 1910), especially in the Slavonic countries. All sorts of works, scientific and philosophical, related incidents and cases of those unfortunate people who became afflicted with vampirism and sucked the blood of men and animals. Up to this time,

although bats were associated with supernatural happenings, they were not associated with vampirism. Slowly the tradition of vampirism added the bat form to its list and later fiction, founded on vampirism, included allusion to bat wings, batlike movements and the actual bat form as portrayed in the really classic Dracula (Stoker, 1929).

Early naturalists visiting Central and South America arrived there with definite knowledge of a bat of some sort that fed upon blood. The exact bat was unknown. This led to various inferences. The ugliest and largest bats were thought to be the vampire. Actual observations of these early travelers, thrilled by the strange New World Tropics, appear to be in the minority as compared to the acceptance of tales they heard, or their deductions from dead specimens. Hence, we find in the old records weird descriptions of vampires hovering over their sleeping victims, fanning them with their wings to induce profound sleep, inserting long tongues in the vein and sucking the man or beast dry.

TAXONOMY

The actual vampire was accorded a place in the formal, binomial lists before it was individually known to be a sanguineous bat. Prince Maximilian Wied (1826) separated the vampire from the genus *Phyllostoma* of E. Geoffroy and placed it in a separate genus, *Desmodus*, with the specific name of *rufus* in 1826. This application of a new specific name in the removal of the vampire from *Phyllostoma* failed to hold, as Geoffroy had already established the species as *P. rotundum* in 1810.[5] The generic separation, however, was clearly indicated by the specialized dentition, although *Desmodus* still retained a place in the family of spear-nosed bats, Phyllostomidae. Waterhouse (1839) referred to the vampire as *Desmodus d'orbignyi*. Wagner (Schreber, 1840) proposed the specific name of *murinus*. To bring the taxonomy to date we quote from Osgood (1912):

> In selecting specimens of *Desmodus* for comparison, I find a noticeable difference in size between examples of typical *D. rotundus* from Paraguay and specimens from Mexico and Central America. In typical *rotundus*, the forearm measures 60–64 mm, while in Mexican and Guatemalan specimens the maximum is 55. A corresponding difference is shown by the skulls. It would seem advisable, therefore, to recognize a northern subspecies, using Wagner's name *murinus* (suppl. Schreb. Saügth., vol. 1, p. 377, 1840), which would stand as *Desmodus rotundus murinus* Wagner.

It now appears that the only known sanguineous bats of the world occur in the American Tropics, forming the family Desmo-

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[5] Geoffroy, E., Ann. Mus. Hist. Nat., p. 181, 1810.

dontidae. This is composed of three genera, each with a single species, as follows: *Desmodus rotundus rotundus* Geoffroy; *D. rotundus murinus* Wagner; *Diphylla centralis* Thomas, and *Diaemus youngi* (Jentink).

The habits of *Diaemus youngi*, appearing to be a rare species, have not as yet been authentically noted. The dentition, however, points to it being of similar habits to the two former sanguineous species.

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PLATE 1

Head of vampire bat, *Desmodus rotundus murinus* Wagner. The specialized dentition includes sharp upper incisors for lancing and inducing a flow of blood, the crowding backward of the upper canines, and separation of the lower incisors to form a channel for the narrow and elongate tongue.

1. Spear-nosed bat, *Phyllostomus hastatus panamensis* Allen. This is the position assumed by the greater number of bats in traversing horizontal surfaces. Such bats, when seeking to fly, usually ascend a vertical surface, in inverted position, before taking wing.

2. Vampire bat, *Desmodus rotundus murinus* Wagner. The quadrupedal gait, with body well elevated from the ground, illustrates how the animal lightly stalks and maneuvers over the body of its victim.

3. The position of the thumbs, turned outward and serving as padded feet on the wing stalks, illustrates the facility of the stalking gait. From this position a vampire bat can leap upward and take flight.

Photographs by Arthur M. Greenhall

Positions assumed by the vampire bat, *Desmodus rotundus rotundus* Wagner, in clinging to an animal with thick pelage. The claws of the hind feet grasp the hairs of the victim's body and enable the bat to move nimbly over vertical surfaces.

PLATE 4

1. Vampire bat. *Desmodus rotundus murinus* Wagner. The beginning of a nightly meal of defibrinated blood. The contents of the dish was consumed in slightly more than 20 minutes, being lapped up by the tongue.

2. Completion of the meal, showing spherical distension of the body. The action of the tongue is shown.

3. Preparing to leap upward for flight; this is preceded by a slight bending of the limbs.

SOME OF THE COMMONER BIRDS OF CEYLON

By Casey A. Wood

[With 9 plates]

During a residence of nearly 3 years in Ceylon I made many excursions to various parts of that remarkable island chiefly for the purpose of studying its flora and fauna—especially its ornithology. On some of these adventures I was accompanied by informed archeologists and naturalists, much to my advantage. Several journeys through forest and jungle were made in company with the well-known Colombo artist, G. M. Henry, who made from live subjects a large number of avian portraits, many of which were loaned by me to the Government and used to illustrate the four volumes issued by it and entitled "Coloured Plates of the Birds of Ceylon." From this source are derived the illustrations in this and other papers by me contributed to the Annual Reports of the Smithsonian Institution.

The Report for 1934 contains a paper, with five plates, in which I endeavored to describe and portray a few of the more curious and rarer Sinhalese avifauna. This list was confined to indigenous species and, although it by no means exhausts the list of species peculiar to the island, it now occurs to the writer that a brief and illustrated account of some of the commoner Ceylon birds would interest the reader.

As pointed out in the 1934 report, the Ceylonese avifauna is large. The extreme length and width of the island are only 270 by 137 miles and yet it is accredited with 52 peculiar and over 320 migrant or semimigrant species. Wait, the most reliable modern authority on the subject, tells us that 20 species may be classed as oceanic wanderers, and only 125 forms are entirely migrant. About 40 of the latter have been recorded on few occasions, but about half of the migrants are common and familiar birds.

Probably the geographic position (6° north of the Equator) and the resultant climatic conditions of Ceylon have most to do with the great variety and number of its avian species. The many waders and water birds are of course largely accounted for by its insular status, but to this explanation must be added the fact that Ceylon is a land dotted over with thousands of artificial "tanks" and lakes varying in area from a few acres to hundreds of square miles.

These stretches of both fresh and salt water support a wonderful variety of ducks, storks, flamingos, teal, spoonbills, herons, egrets, and ibises.

As for the land birds, there is as great a variety, among them two species of tropical crows, toucans, the edible swift, snipe, jungle fowl, partridge, and quail. This avian roster also includes eagles, hawks, and owls, but the most beautiful plumage is found in many of the commoner birds whose congeners live in the New World—notably the orioles, kingfishers, flycatchers, sun birds (first cousins of our humming birds) wild pigeons, and parakeets.

Probably the fact that the majority of the Sinhalese are orthodox Buddhists, opposed to the killing of any form of avian life, and the really operative laws for bird protection account for the great number, variety, and persistence of the beautiful avifauna.

Fifty of the fifty-two species of birds peculiar to the island have been described and pictured by G. M. Henry, in Coloured Plates of the Birds of Ceylon, 3 vols., 1927–30, mentioned above. To this monograph has been recently added a fourth part (with 16 colored plates) by the same author-artist, from which the illustrations of this paper have been taken.

Ceylon robins.—As frequently happens in most of the British Colonies, English vernacular names have been given to both alien and indigenous animals (birds especially) that do not belong to the synonymous species or even genus, although they generally present some resemblance in size, appearance, or habits to the familiar English name. This is true of the "robins" as well as of many other birds well known in Ceylon.

The black robin (*Saxicoloides f. fulicata;* see pl. 1) is one of the prettiest birds in the whole island, where it is everywhere visible; in fact, it is one of the most attractive species the tourist is likely to encounter—an alert, fearless, cheerful little bird with the chirp and the active movements of his namesake. One notes in particular the jerky movements and elevations of his square-cut tail. The entire body of both male and female is of a glossy blue black, with a white patch on the wing coverts. Its length is only 6.3 inches. The bird seems to spend most of its time in searching for the insects on which it feeds. This small creature has little or no fear of man, and one may discover its nest of hair, moss, rags, and twigs with (usually) two eggs in any convenient cavity or space about a house, in a coconut shell, or in some hole in a bank.

The Ceylon magpie robin (*Copsychus saularis ceylonensis*) is also found in Malaya and India. It closely resembles the black Indian robin in habits, size (length, 8 inches), and color markings except that the proportion of white on the wings and abdomen is greater than in the last-named species (pl. 2).

This pretty bird (both sexes are much alike) has the habit of running along the ground, suddenly stopping and then jerking its tail in the air while the wings and tail are at the same time fully spread. It differs from the black robin in that the male has a delightful, prolonged and varied song that he sings both in the early morning and late in the evening.

Ceylon bulbuls.—Any dictionary will inform you that the term "bulbul" is of Persian origin and was originally applied to a species of nightingale, probably *Luscinia hafizi*, whose glorious song is celebrated in oriental verse; but there is very little about the cheerful but interrupted warble of any of the six beautiful Ceylon bulbuls likely to found a claim to the rank of avian prima donna. Yet they are all very attractive birds.

Probably the most interesting variety is the charming little Madras red-vented bulbul (*Molpastes c. cafer*, pl. 3) with the head, chin, and throat a deep black, the neck, back, wings, breast, and rump various shades of brown, and under tail coverts crimson. The sexes are much alike; length, 7.8 inches. The species is found over most of Asia. Like the "robins", this bird is a fearless little creature, frequenting human habitations in and about which it builds its small, cuplike nest. It also favors the hedges, shrubs, and low trees of gardens as a nesting place. The Madras bulbul has a cheerful little warble but not much of a continuous song. My niece had a male Madras bulbul which she reared from the nest, took with her all over the Far East for several years, to find eventually a welcome residence in a Los Angeles aviary.

Ceylon bee-eaters.—This beautiful and extremely interesting avian group is found almost everywhere in the Old World. Their predominant color is green, varied in the species by artistic markings of other colors. They are all small, slim birds with long, slender, gently curved, pointed bills, and in the Ceylon species the nostrils are partly covered with feathers, with a few bristles at the base of the bill.

All species feed on insects—chiefly bees and wasps that they hunt on the wing—the capture of their prey being announced by an audible snap of their mandibles. As a rule they choose for a lookout some prominent limb of a tree or a telegraph pole, whence they dart upon any luckless bee that passes by, returning to their post to swallow the dainty morsel. It is quite likely that the honey with which the quarry may be laden is very acceptable to the bird. Bee-eaters burrow into river, creek, or other banks for nesting purposes, driving a long unlined tunnel, at the end of which are laid their white eggs, following the common rule that eggs laid in dark holes are white.

The blue-tailed bee-eater (*Merops superciliosus javanicus*), a migrant to Ceylon and found over most of the Asiatic Continent, is shown on plate 4. Its length is 12 inches, and its plumage is a lovely combination of dark green on the upper parts shading into light blue green on rump and tail. The long pair of tail feathers are tipped with black, the chin is yellow, the other underparts showing mixed shades of green, chestnut, and brown. This species generally occurs in small flocks and has a rather pleasant chirrup but no song.

The other pictured variety (pl. 5) is the attractive, particolored chestnut-headed bee-eater [*Melittophagus e. erythrocephalus* (Gmelin)] whose habits closely resemble the blue-tailed species. The sexes are alike in colors; length, 8.5 inches; upper parts mostly chestnut, wing and coverts green; rump and upper tail coverts blue green; chin and throat yellow. The bill is black, iris crimson, legs and feet dark brown. This species, according to Wait, prefers as a hunting ground the rivers and tanks, and uses as a watch tower the branches of trees lining the banks. From these points of vantage the birds secure their quarry on the surface of the water, including small fry of all sorts.

Ceylon swallows.—The representative swallow pictured here (pl. 6) is *Hirundo daurica hyperythra*, known as the Ceylon swallow. It is a beautiful bird, a subspecies peculiar to the island, resembling the other members of this well-known family as it is seen all over the world. Every one of the four Sinhalese species belong to the genus Hirundo or true swallows. The predominant color of this swallow is a glossy steel blue or black; the entire lower plumage is a rufous or pale brown; the iris is dark brown. The most noticeable separate markings are the relatively large patches of brown shaft streaks on the chest and lower back. This bird frequents tanks, paddy-fields, and open country, spending much time hawking for insects, often in company with other swallow species. It does its extremely valuable part in regulating the supply of pests that threaten to make this earth uninhabitable for man. I wonder how long the races of man would survive if all the swallows, martins, and birds of similar habits were suddenly to cease their insectivorous labors.

The Ceylon swallow has a loud twittering warble usually uttered while on the wing. It may usually be distinguished from other swallows when in company hunting because of its lower, slower, and heavier flight. The nest is a bottle-shaped structure of solidified mud attached to the under surface of an arch, overhanging rock, roof, or cave. It is lined with feathers and in it are laid two or three white, elongated oval eggs.

Ceylon kingfishers.—The beautiful little kingfishers whose portraits appear in the accompanying plates present in large measure the outward appearance and habits of this world-wide family. Only

one genus, *Ceryle*, is found in America. Most varieties are fish-eaters, though some species add to their diet or feed chiefly on insects, lizards, and other food not living in or on the water. They all lay their eggs in a tunnel excavated, like the bee-eater's nest, in a bank generally near water. In it are laid round, glossy, white eggs. Ceylon is abundantly supplied with these lovely birds, seven species, of five genera, being found on the island, four of which are rather common.

The lovely little three-toed kingfisher (*Ceyx e. erithaca*, pl. 7) is rather a rare variety, found also in Malaya and parts of India. It is sometimes seen singly instead of the usual pair, on the banks of forest streams, where it patiently awaits the advent of frogs, crabs, or small fish. It digs a tunnel in the bank of a stream and lays therein three small white eggs.

Wait draws attention to the **V**-shaped black mark washed with purple on the forehead at the base of the upper mandible, and adds that the crown, nape, hind-neck, lower back, rump, and upper tail coverts are deep orange-red with a metallic lilac gloss—a wonderful display of gorgeous color. The remainder of the body is a medley of brilliant cobalt blue, dark brown, and yellow. The length of this small bird is only 5.35 inches, the long bill, legs, and feet being coral red. The flight is very swift and the bird utters a shrill piping note as it darts along.

Another beautiful species is the white-breasted kingfisher (*Halcyon smyrnensis generosa*), which has a blood-red bill, brown iris, and coral-red legs (pl. 8). The predominant color of this charming bird is (upper parts) bright blue, and the breast and chin are white. The length is 11 inches, twice that of the three-toed variety, the bill being 2.6 inches from the gape. It is a common bird all over the island, where it is seen on swamps, rivers, tanks, and paddy fields. It feeds on lizards, the larger insects, worms, and frogs, as well as on fish and crabs. It emits on the wing a loud rattling cry and during the breeding season often perches on the top of a tree, sounding now and then a peculiar whinnying note. The nest is the usual hole in a bank, in which are laid several round, white eggs. The sexes are nearly alike.

The owls of Ceylon.—These nocturnal and very distinctive birds of world-wide distribution are well represented on the island, at least nine varieties being generally regarded as Sinhalese. Like owls in other parts of the earth, the feathers are fluffy and soft, the head being large and closely covered.

The owls have large, humanlike eyes, adapted for seeing well at night and in gloomy places. The visual organs are protected and assisted in sight by encircling disks of stiff feathers that are occasionally decorated.

The species about to be described has, like many others, upstanding and movable ear-tufts or "horns." The upper mandible is short, curved, and hooked, indicating the bird of prey. The ear openings are large and, in some species, protected by a lid or operculum. The legs are those of most carnivorous birds who live by aerial hunting—strong and feathered to the toes, which carry short but very sharp, incurved claws.

In Ceylon, as elsewhere, the ghostly habits, the big eyes, the weird hoots, shrieks, and other startling night cries of these birds have given them a bad reputation, although among the Greco-Romans the owl was regarded as a bird of wisdom and the particular pet of Minerva. In the Indian and Ceylon forests, however, the "devil bird" is generally supposed to be an owl. Certainly it is one of these avian species that emits the strangulated, terrifying screams which spread terror through the stilly night over many a village whose superstitious inhabitants regard the demoniac cries as omens of approaching evil.

The collared scops owl (*Otus b. bakkamoena*), whose portrait is here reproduced (pl. 9), is the most familiar of all the Ceylon species, and because it does not avoid man, this little owl is the best known and least persecuted of its kind on the island. The birds mate for life, live in pairs, and are strictly nocturnal, hiding in thick woods during the day and appearing at dusk to hunt for food. They subsist mainly on such insects as beetles and grasshoppers, also keeping a sharp lookout for the smaller lizards and mammals. The flight of this bird is noiseless and very swift.

The predominant coloration of this bird is grayish brown, tinged with yellowish. The facial region, including the erected tufts, is whitish, marked with dark pencilings. Some specimens are grayer (or more rufous) than others. Length, 8 inches; iris a yellow-red or chestnut.

Two eggs (of a dirty white color) are laid, as a rule, at the bottom of a hole.

It is only when alarmed or surprised that the collared scops owl raises his long ear tufts, as shown in the present illustration. When in a quiet state of mind the horns are lowered and the bird appears to have a smaller and more rounded head.

PLATE 1

THE BLACK ROBIN.

PLATE 2

THE CEYLON MAGPIE ROBIN.

PLATE 3
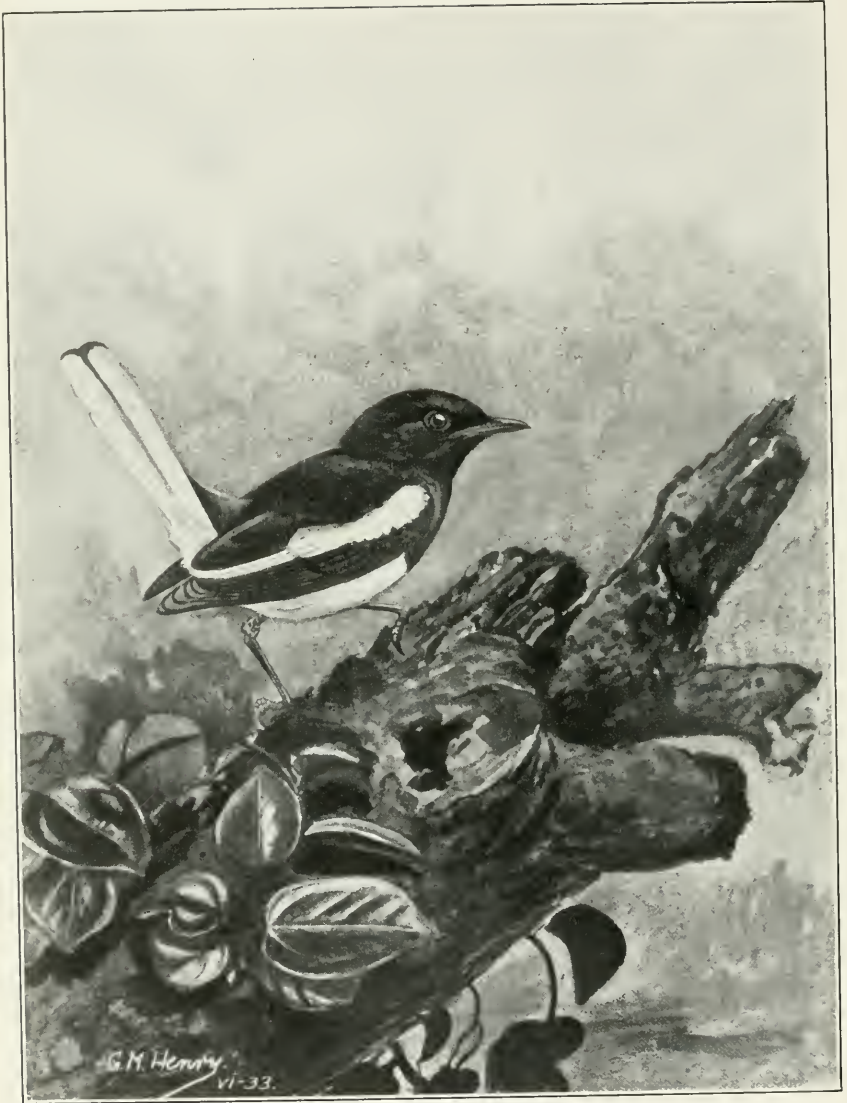
THE CEYLON RED-VENTED BULBUL.

PLATE 4

THE BLUE-TAILED BEE-EATER.

PLATE 5

THE CHESTNUT-HEADED BEE-EATER.

PLATE 6

G. M. Henry

THE CEYLON SWALLOW.

PLATE 7

THE THREE-TOED KINGFISHER.

PLATE 8

THE CEYLON WHITE-BREASTED KINGFISHER.

THE COLLARED SCOPS OWL.

THE WAX PALMS

By Miriam L. Bomhard

Botanist, United States Forest Service

[With 4 plates]

If the plant kingdom were a monarchy in which but a single family of plants had the hereditary right to rule, the palms would unquestionably hold this honored position. The great naturalist, Linnaeus, in a rather whimsical "social" ranking of the plants of the world, placed the palms first, further distinguishing them as Principes, the princes or rulers, whereas certain other groups were merely plebeians, patricians, and so forth.[1] It is interesting to note that this term, Principes, continues to appear from time to time in publications as a synonym for the family name of the palms (Palmae or Palmaceae). Although Linnaeus knew only 15 species, whereas at the present time the family includes from 1,600 to 3,000 kinds of palms, the discovery of new species has in no way minimized his estimate of their "social" prominence.

Such high acclaim is not accorded the palms because of unusual evolutionary advance or complicated flower structure. The family is relatively old, and, judging from fossil evidence, seems to have changed scarcely at all for long ages. The eminent paleobotanist Dr. G. R. Wieland, writes me that, "It is not determinable how early the palms began as a distinct type but the time must be set very far back. By Upper Cretaceous time, the group had reached giantism and adorned the dinosaur landscapes." The flowers are small and relatively simple, being built on the plan of the lilies. It is the general appearance, the tout ensemble, of the palms which is so striking and distinctive. They are predominantly trees, usually character- ized by a tall, straight, unbranched, beautifully proportioned trunk topped by a massive crown of handsome fanlike or plumelike leaves. To be sure, not all members of the family have this traditional ap- pearance. One genus, which includes the Egyptian doum palm (*Hyphaene thebaica*), is unique in that its members have a much-branched trunk. Many palms are vines—a good example of climb- ing palms are the species of *Calamus* whose stems furnish the com-

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[1] Linnaeus, Car. Systema Naturae, ed. 12, vol. 2, pp. 3-4, 1767.

mon rattans of commerce. Some palms, such as the graceful yellow palm (*Chrysalidocarpus lutescens*) often used for indoor decoration, from clumps composed of several stems. *Nipa fruticans*, of Indo-Malayan marshes and estuaries, is representative of certain plume-leaved palms which have a creeping stem; the huge, erect leaves, arising from this stem, resemble giant feathers, sometimes 30 feet in length, which appear to come directly from the ground. Still other species, such as the dwarf palmetto (*Sabal minor*) of the south-eastern United States, are low, even shrubby plants, apparently possessing no stems whatever. However, the wax palms with which we are here concerned are not only beautiful columnar trees but are probably the most remarkable palms in the world. They far exceed the most hopeful anticipations of the palm enthusiast; they are the princes of the "Principes"!

Try to imagine a palm having a slender, smooth, shining, alabasterlike trunk which rises, shaftlike, 200 feet and more straight into the air and bears at its summit a crown of feathery, silvery green leaves nearly 20 feet in length. Then visualize it standing either solitary or in company with others of its kind at nearly 10,000 feet above sea level, within sight of perpetual snow. This is the tallest and most amazing of all the wax palms of the high Andes Mountains—it is the wax palm of the Quindío Pass in Colombia.

The various kinds of wax palms, at present united under the genus *Ceroxylon*,[2] are now known to be widely distributed along the length of the Andes, occurring mainly at remarkably high altitudes, from Venezuela and Colombia into southern Peru (see map, fig. 1). In Index of American Palms (Dahlgren, 1936), 16 species are recorded as being in good standing; some of these are probably not specifically distinct, but on the other hand this most interesting group of palms has never been carefully studied and doubtless many more species remain to be discovered.

There are two outstanding reasons why the Quindío wax palm just mentioned as well as certain other species are exceptional in the palm family: First, the altitude at which they grow; and second, the tremendous height they attain. Palms, as every one knows, belong, preeminently, to warm, moist regions. Although some of them are natives of the warmer temperate climes—familiar examples are the cabbage palmetto (*Sabal palmetto*), well known in the Carolinas, Georgia, and Florida as well as in the Bahamas, and the Mediterranean fan palm (*Chamaerops humilis*) of southern Europe and northern Africa—the family as a whole attains its best development

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[2] The various species of wax palms have been described under *Ceroxylon, Iriartea, Klopstockia,* and *Beethovenia.* For the sake of clarity in this article, the specific names appear alone with the terminations as under *Ceroxylon,* but Humboldt's species, the type of the genus, appears as *C. andicola.*

FIGURE 1.—Distribution of wax palms in the Andes of South America. Map outline and topography taken from Rand McNally's Commercial Atlas, ed. 62, 1931, and from A. K. Johnston's The Royal Atlas of Modern Geography, 1906. The map is intended merely to inform the reader of the widespread distribution of the wax palms. The specific names are in accordance with the most recent treatment.

in the Tropics. In fact, they have come to be symbolic of equatorial regions. The very mention of the word "palms" seems to conjure up a vision of bright and sunny lands where the vegetation is luxuriant, the air warm, balmy, and sweet-scented, and where the spell of enchantment and romance seems ever present.

There is a well-nigh universal law concerning the distribution of plants which recognizes that a decrease in temperature, going from the Equator toward the Poles, has the same effect upon vegetation as an increase in altitude above sea level. A certain type of vegetation would naturally be able to exist at a higher elevation in the mountains of the Tropics than in those of a temperate zone. The general altitudinal limit of the palm family as a whole is somewhat less than 4,000 feet. What an amazing thing it is to find that the Quindío wax palm exceeds this upper limit by about 6,000 feet. In fact, there is another species of wax palm growing at the Volcan Chiles, on the boundary line between Colombia and Ecuador, which exceeds even this altitudinal record. Since it averages 40 to 50 feet in height, it must be regarded as relatively small in comparison with the Quindío palm, but it is found up to 13,450 feet above sea level; that is, almost 2 miles higher than palms can ordinarily grow.[3] The fact that the Quindío wax palm grows at such a high altitude where the mean annual temperature is between 12.5° and 18.5° C. (54.5°–65.3° F.) appears to be ample justification for describing it as "the palm of the frigid region par excellence" (André, L'Amérique Équinoxiale). However, except for the species at the Volcan Chiles, the wax palms are not strictly alpine plants, but belong rather to the cool temperate zone.[4]

It is also a matter of common observation with regard to the behavior of woody plants that, when some few representatives of a family are able to maintain themselves beyond the ordinary limits of the majority of the group, they are dwarfed or lacking in vigor— stunted, bushlike vegetation is characteristic of the upper limit of trees the world over. The logical supposition would be that any species of such a tropical family as the palms growing at such extraordinary altitudes and enduring the low temperatures just mentioned would, of necessity, be low, weak, and rather poor specimens, making the most of a bad situation. But the wax palms of the Quindío Pass are the tallest palms in the world. When this species

[3] Several smaller palms of other genera are known from fairly high altitudes.

[4] It is definitely stated in Chapman. F. M. (The distribution of bird-life in Colombia ; a contribution to a biological survey of South America, Bull. Amer. Mus. Nat. Hist., vol. 36, p. 85, 1917), that the altitudes of the various climatic zones are given as higher than those based on temperature alone. The "tierra templada" becomes the subtropical and the "tierra fria", the temperate zone. The wax palms on the eastern slope of the Quindío are mentioned rather surprisingly in the subtropical as well as in the temperate zone in this work (p. 29).

was first discovered 135 years ago, these trees were the tallest living plants known. The very first description noted finding palms 177 feet high, but this estimate was subsequently proved to be an understatement since they often reach 200 feet and may possibly occasionally reach a maximum of more than 250 feet. It may be of interest to point out that the tallest living trees at the present time are numbered among the redwoods and the eucalypts—a redwood (*Sequoia sempervirens*) 364 feet high holds the record among living trees.[5] At the beginning of the nineteenth century the redwoods were unknown to science and the tallest of the eucalypts had not yet been discovered.[6]

It should be noted that palm species are usually described as tall when their trunk height attains 60 feet or more. The fact that the trunk is unbranched has the effect of making many palms appear taller than they are by exact measurement. A general notion of the tremendous height of the wax palm of the Quindío Pass may be gained by a comparison with two of the most impressive palms, from the standpoint of height, to be seen within the borders of the United States: the royal palm (*Roystonea floridana*) of southern Florida and the Mexican Washingtonia (*Washingtonia robusta*), native to Lower California and Sonora but introduced and much planted in California, the Southwest, along the Gulf Coast, and in Florida. Both of these occasionally measure 100 feet in height (perhaps more). At least four species of wax palms now known are nearly twice as tall and the Quindío wax palm may even exceed this.

Is is also of interest that palm flowers, although individually rather small, are borne in such great numbers on the flowering branches as to form usually rather showy sprays or clusters. The flowering branches first develop enclosed in one or more leaflike structures called *spathes*, from which they emerge when the flowers are about to open. The spathes may remain on the tree even after the flowers have formed fruits. The characteristics of the flowers and fruits, the branches on which they are borne, and the spathes are very important to an understanding of the various species of palms.

It was in October 1801 that Alexander von Humboldt, worldtraveler, cosmographer, and one of the most renowned naturalists of all time, undertook the difficult journey over the Quindío Pass. He was accompanied by his botanical associate, Aimé Bonpland. It was on this journey that Humboldt discovered the first species of wax

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[5] Tiemann, Harry D., What are the largest trees in the world? Journ. Forest., vol. 33, no. 11, p. 903. 1935.

[6] Although *Sequoia sempervirens* was discovered by Archibald Menzies near San Francisco Bay in 1796, the redwoods were not known in English gardens until 50 years later; the genus was first published in 1847.

palm. He named it *Ceroxylon andicola*, the wax palm of the Andes. It was already known locally as the *palma de cera*. The genus name, *Ceroxylon*, comes from two Greek words, *kēros* (beeswax) and *xylon* (wood); the specific name, *andicola*, means of or belonging to the Andes. Humboldt at once remarked the unusual character of this palm—the high altitude at which it grows; its towering height, constituting, as Humboldt said, "a forest above the forest"; and the fact that the trunk is coated with a shining white wax, making it look like an alabaster column. Nothing like it had ever been known.

Perhaps no high mountain pass in South America is more renowned than the famous Quindío Pass, for hundreds of years one of the principal routes of travel across the Andes north of the Equator (the pass is located at 4°36′ north latitude). The Central Cordilleras separate the waters of the Cauca River on the west and the Magdalena River on the east. The Quindío Trail connects the towns of Cartago on the west and Ibagué on the east, the crest of the trail being at about 11,435 feet above sea level (see André's map, fig. 2). Somewhat to the northeast of the pass, the snow-capped peak of Tolima rises to an altitude of 18,432 feet. Tolima is probably the most elevated of a cluster of peaks in this part of the Central Cordilleras, if not the highest peak in Colombia. The descriptions of this trail written by various travelers make fascinating reading; it is particularly interesting to compare the impressions and experiences of these explorers and to note that individual accounts, covering a period of more than a century, agree concerning the great beauty of the region traversed and the difficulty of the passage.

The following is a rather recent description of the trail: [7]

We are now [leaving La Balsa on August 8, 1913] well started on the Quindío trail which, beginning at Cartago on the edge of the Plain of Cali, 2,950 feet above sea-level, climbs 8,400 feet in a distance of 42 miles, and, crossing the Central Andes, or Cordillera del Quindío, at a local depression called the Boquerón or opening, descends to Ibagué (4,200 feet) on the edge of the great sloping plains of the Upper Magdalena. The distance along the trail between the two cities is only about 75 miles, but such is the character of even the "improved" trail of today that it is a good 3 to 4 days' journey even under the best conditions. In dry weather it is not particularly difficult, but its character during times of rain is such that it has an unenviable reputation throughout the length and breadth of Colombia, and even into Ecuador. In the northern part of the Cordillera del Quindío it rains during April, May, and June; there is then, in July, a slight break, or "short summer", then rain for August, September, and October, and then a "long summer" of dry weather running through November, December, January, February, and March.

Humboldt's journey over the pass in 1801 is graphically described in Vues des Cordillères, published in 1810, although first mention of the wax palm is found in Essai sur la Géographie (1805). At the

[7] Veatch, A. C., Quito to Bogotá, p. 201, 1917.

FIGURE 2.—The Quindío trail. After André.

time of Humboldt's crossing there were no towns, not even isolated huts, the whole length of the trail between Ibagué and Cartago, and there was no means of subsistence, so that it was necessary to take supplies for a month under the fear of complete isolation because of rains and the possibility of being unable either to go ahead or return. Humboldt made the journey on foot, followed by 12 oxen which carried his instruments and collections. He seems to have spurned being carried on the back of a native porter, or *carguero*, which was the customary method of travel over the Quindío at that time, but he describes both the *cargueros* and the means of conveyance at some length. Transporting persons across the trail was the regular and honored profession of several hundred men of that region. One traveled by *carguero* here as one would travel by horseback in other places. The voyager was carried seated in a sort of bamboo chair attached to the back of the porter by straps passing over the latter's forehead and under his arms. These *cargueros* were hired for a lump sum for the entire journey which might take from 10 to 25 days, depending upon the season and condition of the trail. Humboldt does not give the exact duration of his trip, but says that 10 or 12 days should be sufficient for the journey. He describes the route as being little more than a narrow path, made up of hazardous ascents and descents, and only 16 to 20 inches wide in some places— "for the most part resembling a tunnel left open to the sky." He states that the journey was very fatiguing and describes the difficulty of keeping his footing in the thick mud, full of deep holes made by the oxen, of wading through icy streams, how his shoes were worn off so that he had to go barefoot and his clothes were torn by spines of the thick undergrowth, and of 3 or 4 days of such torrential rain on the west side of the pass that a forced stop had to be made. Shelter on the journey was obtained in hastily constructed cabins. The framework was cut from the surrounding vegetation and erected on the spot, but the waterproof thatch roofs, made of the leaves of a bananalike plant, were a part of the regular equipment of the trip. These were carried rolled up like a carpet and were spread out whenever it was necessary to roof the cabins. Humboldt says that, should the roof leak, it was only necessary to add another leaf.

Humboldt published a botanical description of *C. andicola* in Plantes Équinoxiales (1808) with illustrations showing the habit of the palm as well as a separate drawing of the flowering stalk emerged from a single spathe and detailed delineations of the flowers. In this and other publications he gives definite data as to its native habitat in the Quindío region (on the eastern side of the pass). He also explains its altitudinal distribution, particularly with reference to the upper and lower limits of certain oaks and some of the cin-

chonas. Incidentally, this was a time of great interest in and exploitation of the various species of cinchona of Andean South America. The properties of quinine had become well known, and many botanical explorers of the first half of the nineteenth century, including Humboldt, made valuable contributions to the knowledge of the distribution and character of the species of cinchona.

Probably no botanical explorer from the illustrious Humboldt's time until today would think of making a collecting trip in South America without having thoroughly familiarized himself with Humboldt's descriptions. Certainly, the botanists of the past century studied his accounts assiduously. But, strange to relate, it seems more than probable that Humboldt mixed two species of palms in his account of *C. andicola;* he gave the type locality on the eastern slope of the Quindío and then apparently figured a very different palm. This might easily have happened considering the difficulties under which he traveled and bearing in mind that there are wax palms on both slopes and in other portions of the Andes. Let us put ourselves in his place for a moment! We have come to some marvelous wax palms growing at a very high altitude and note the location; the road is treacherous and slippery and the 12 oxen, steadily climbing steep slopes over a miserable trail, are already loaded down with baggage and plant collections; we ask the guides whether these palms continue on the other side of the pass and are assured that there are just as many beyond the crest; supposing the eastern portion of the trail to be the most difficult part, it seems best to delay the collection of specimens and data on the palm itself until we have come to the less hazardous descent on the western slope!

We know that Humboldt was delayed by torrential rains for several days after the Boquerón had been crossed and that he was quartered in one of the cabins protected by the waterproof roof. Did he describe the palms that surrounded him then, thinking them the same as those he had seen on the eastern slope? Did he figure from memory a wax palm which he saw elsewhere? We shall never know. It is only possible to advance speculations such as the foregoing in an attempt to explain the disturbing discrepancies in Humboldt's illustrations and accounts as compared with the findings of subsequent travelers. In the original description of *C. andicola*, it is stated that Humboldt sketched the palm on the spot. There is, however, no corroboration by persons who have since crossed the trail that such a palm as that figured—it has a bulge in the trunk and the spathes are distributed here and there in very unorthodox fashion—exists on the eastern side of the pass nor is it easy, in the light of information at hand, to identify it with a wax palm on the western slope! We have the word of Baron von Thielmann in Vier Wege durch Amerika (p. viii, 1879) that Hum-

boldt unfortunately was forced to make the latter part of his South American explorations (the years 1799 to 1803 were spent in South America) more hurriedly than the earlier portion of his journey so that he wrote much of this account after his return to Europe. Moreover, Von Thielmann, recounting his own journey over the Quindío, states in a footnote (p. 366) that Humboldt's illustration in Vues des Cordillères of the entrance to the trail at Ibagué must have been done by him "from memory since it by no means corresponds to the actual conditions." Be that as it may, Humboldt did see the Quindío wax palm in all its majesty, and the credit for its discovery cannot be taken away from him in spite of the confusion in his descriptions and drawings of it.

However, it is fortunate that there are several accounts, particularly in the writings of André, Karsten, and Von Thielmann, which throw considerable light upon the character of the wax palm of the eastern slope. Eduard André tells of his crossing of the Quindío in March 1876 in a series of articles on his travels in equatorial South America (L'Amérique Équinoxiale, 1878–79), published in a well-known illustrated magazine, Le Tour du Monde. André was an able botanist, for many years editor of L'Illustration Horticole and a contributor of papers on various botanical subjects. He was well acquainted with Humboldt's work and crossed the trail in the same direction and over the exact route that Humboldt took, that is, from Ibagué to Cartago André writes most entertainingly. He describes the trail and his experiences—*cargueros* were no longer used in 1876—he tells of the people he met and discusses the types of vegetation, especially with reference to the changes in altitude. He describes the bamboos, the oaks, and cinchonas, various palms and ferns, and, most important of all, for us, the wax palms. He compares his own observations with those of Humboldt practically every step of the way but, even at that, had it not been for the fact that he arose too early one morning for a hunting expedition, we might just possibly be without his accurate observations concerning the magnificent wax palm on the eastern side of the pass and his statements regarding the one of the western slope. André is the first traveler, as far as I have been able to discover, who definitely stated from actual experience that two kinds of wax palms occur on the two slopes of the pass. Moreover, André actually chopped down two of the taller palms on the eastern side and not only measured them but collected botanical specimens as well.

André had been told that the journey would take 7 days; it took 10. During the 75 years that had elapsed since Humboldt crossed the trail, a few huts, a sulphur mine, and other localities marked definite stopping-places along the route, all of which André set down in his maps (fig. 2). Approaching Pié de San Juan, André

writes, "There in a thick vapor, a splendid vegetation unrolled before our eyes: The first *Ceroxylon* appeared, reigning over a population of ferns, tacsonias, beautiful orchids * * * " and, as he continued toward Las Cruces and Gallegos, "The wax palms (*C. andicola*) appear finally in all their majesty, their feet in the water, their heads in the clouds. They form forests (*palmares*) of columns which look from afar like ivory, crowned by a sheaf of leaves 5 to 6 or more meters [16 to 20 feet] in length" (pl. 1).

André finally arrived at Las Cruces "in a state of fatigue, filthiness, and tatters, impossible to describe" and was amazed to find that the dwelling which marked the spot and where he was to spend the night was a trim and fairly extensive place, the hacienda of Ramon Cardenas. Ramon's house, although architecturally similar to other houses in Colombia, was built almost entirely of the wax palm. The uprights, instead of being made of whole or split bamboo like the houses of warmer regions, were of this palm still covered with the wax and looking like marble columns encircled by brown rings;[8] in fact, "the entire framework was of the same palm wood, supple, strong, and durable." "The roof, covered by the enormous leaves, silver beneath, caught strange shadows, and made a warm and impenetrable cover." André does not specifically state that the "strange shadows" were caused by the flicker of the candlelight and that the candles were also made from the wax palm, but this was probably true since Ramon's income from agriculture and hunting was augmented by selling the wax which his men scraped from the palms. This he sold in Bogotá. The wax is usually scraped from living trees but sometimes the palms are felled first. Humboldt and others tell of this use of the wax for candles and matches and Humboldt suggested its commercial possibilities. The wax burns with a clear bright flame.

Ramon seems to have been so complimented by his learned visitor's interest in the jaguar skins which adorned his dwelling that it was arranged to go hunting the next day. André writes that, after several hours of sleep, he was awakened by the cold. He looked at his thermometer and noted that it was 2° C. (35.6° F.). He decided to walk about outdoors. In the moonlight, the wax palms looked like "svelte pillars of a cathedral; no breeze stirred the foliage of their majestic crowns, which shot up 60 meters into the air." He continues: "This silence, this impressive calm, in such a place, in the middle of the night, stirred my soul with an emotion which I did not try to combat and which I shall never be able to forget." André soon learned that,

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[8] The bases of palm leaves completely encircle the stem in the early stage of development; if the internodes elongate rapidly as in the wax palms, a ring or scar is left completely around the stem when the leaf falls off.

contrary to the custom in Europe, the chase was not begun early in the morning because of the darkness and the denseness of the jungle and so, while waiting for breakfast and the completion of preparations for the hunt, he took several men and set forth to cut down some wax palms. Two palms were finally felled. "I measured one of them: It was 60 meters in length, its circumference at the base was 1 meter 24 centimeters, and near the summit, 65 centimeters, a remarkable example of graceful proportion for so great a height." This palm which he actually measured was, then, 196.8 feet tall, the diameter being 15.5 inches at the base and 8.2 inches near the top of the trunk. (He writes elsewhere that it attains from 60 to 80 meters, that is, up to 262 feet in height.) The interior of the trunk was white and pithy toward the center, as is usual in palms, but the woody cylinder surrounding the pith was extremely hard. "The wood fibers, torn out by the violence of the shock, stood up on the stump black, fine, and hard as dark steel wires." "Between the shattered leaves * * * glaucous above and white below, the fruiting branches 2 meters [6.5 feet] in length, which had seemed so small to us from the ground, were lying scattered and broken. The innumerable orange berries with a sweet pulp, the size of Chasselas grapes, rolled all over the ground. Many thousands were recovered to be sent to Europe, also some leaves, spathes, and two cross sections of the trunk. From my calculations, these trees were about 150 or 200 years old."

He found that the wax palms on the eastern side of the Quindío trail extended from Mediacion to La Ceja, being most abundant at Las Cruces; the *palmares* "diminished from day to day" as the upper limit of their distribution was approached. This species apparently grows in a restricted area scarcely more than 9 to 12 miles north and south of the trail, the altitudinal range being between 6,560 and 10,000 feet above sea level. Various small palms of other genera, invariably associated with it at first, disappeared at the higher elevations. André was surprised to find that the palms were not in the midst of the oak belt, as Humboldt had reported, but beyond it on the eastern slope of the Quindío. After crossing the crest, however, he discovered that the oaks ascended much higher on the western slope and were there intermingled with wax palms. André observes: "These reasons make me believe that Humboldt has confused the true *Ceroxylon andicola*, that of Las Cruces, with another species, smaller, and still little known (*C. ferrugineum*). It is characterized by the rough surface of its berries, and it abounds in the Andes, principally on the west of the Central Cordilleras and almost into the Republic of Ecuador." (L'Amérique Équinoxiale, p. 101, 1879.) It is unfortunate that André did not describe this species, to which he gave a name, more fully, but there is every reason to believe that his observations concerning a second species are

correct. Specimens of this smaller palm from the western slope of the Quindío, collected by E. P. Killip of the Smithsonian Institution, and Dr. T. E. Hazen of Columbia University in 1922, have berries whose surface is roughened by small pustules; specimens are deposited in a number of herbaria, including the United States National Herbarium. The photograph shown in plate 2 was taken by Mr. Killip near Salento and that in plate 3 on the eastern slope near La Ceja. (See also André's map.) On the western slope the wax palms disappeared at 5,900 feet elevation and were replaced by palms of warmer habitat.

Baron von Thielmann, who journeyed over the Quindío shortly after André, also gives a very detailed account of the trail and the wax palms in his Vier Wege durch Amerika (1879). He points out that although the hardships of the journey have lessened considerably since Humboldt's time, "the hazards for the horseman are still great enough, especially during the torrential rains, of which no month is quite free in the high mountains." He is most enthusiastic concerning this region, for he writes: "In forest beauty of mountain wilds, the Quindío hardly has a rival. The groves of the wax palms are to me the most sublime of all the realm of the plant world." This is, indeed, high praise, but it is the opinion of an experienced world traveler well qualified to make such a comparison. Von Thielmann's descriptions of the locality in which the palms occur and of the palms themselves agree very well with those of André, but he states that the maximum diameter of the Quindío wax palm seldom exceeds 20 inches, which is somewhat greater than that of the palm André measured. He describes the grace and beauty of the trees, their silvery green foliage, and also notes that the fruits are of an orange-red hue. From him we learn that the wax palms achieve their best development when growing as scattered individuals and that they are less tall, averaging only 130 feet in height, when occurring in closed stands. Their growth is rapid, as is evidenced by the wide space between the leaf-scar rings on the trunk. He discredits the fear expressed in Europe that these palms were in danger of extinction, since he saw few trunks lying about on the ground and he found no indication that the wax, although used locally for candles and matches, was of sufficient importance as an article of commerce to suggest the exploitation and possible disappearance of the palms. "As far as the eye can see, the tops of the palms bedeck one mountain slope after another, and around isolated huts I found closed stands of thousands." [9]

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[9] That these wax palms are still abundant and a very characteristic feature of the flora of this region is indicated by the fact that Cuatrecasas lists them as a special ecological unit, the *palmetum,* in his recent study of the geobotany of Colombia. (Cuatrecasas José, Observaciones Geobotánicas en Colombia. Trab. Mus. Nac. Cienc. Natur., Ser. Bot., no. 27, p. 70. 1934.)

Von Thielmann's admiration of the marvelous vegetation and grandeur of the Quindío was not dimmed by the trials of the trail, but he became somewhat exasperated over the necessity of negotiating a continual series of steep ascents and descents out of all proportion to the actual distance accomplished forward at the end of a hard day's going. His remark, "In what condition we finally arrived as night closed in at the huts of Las Cruces, I will not try to describe", is practically an echo of what André wrote concerning his arrival at the same place. Von Thielmann records the gradual disappearance of the wax palm and the "gnarled and parasitical growth" which is characteristic of the region above them near the summit of the pass. Since palms are generally found in the midst of, or bordering, luxuriant vegetation, the fact that the dwarfed and misshapen woody plants typical of timber line here almost immediately succeed the upper limit of the distribution of the wax palms is but a further evidence of their amazing vitality and extraordinary adaptation to such a high altitude. Von Thielmann was interested to find that a little wooden cross marked the crest of the Quindío and that each peon, as he reaches the summit, contributes a small twig or branch to the pile already near the cross—a custom observed on mountain passes throughout the world. It is apparent that he made no independent observations concerning the wax palms on the western slope, since he merely quotes André as to the existence of a second species.

Both Von Thielmann and André wrote travel accounts. However, to André must be given credit for the most complete information concerning the Quindío wax palms presented by anyone up to the present time. André was convinced that Humboldt confused two species; nevertheless he continued to use the name *C. andicola* for the one on the eastern slope and ventured to propose a new name, *C. ferrugineum*, for the rough-fruited species, without later publishing a technical description. In the meantime, another botanical explorer had given a new name to the wax palm of the eastern slope (Karsten, Florae Columbiae, 1858).

Hermann Karsten was a botanist of great renown—his plant discoveries in South America rank, in many respects, as importantly as do Humboldt's. It was Karsten who discovered three new species of wax palms in widely separated regions of the Andes—the first intimation of the extensive range of this group of palms hitherto represented by Humboldt's single species. In addition, he described and launched a new name for the tall species on the eastern slope of the Quindío (pl. 4, left). All of Karsten's palms, although differing in minor details, were similar in the more important botanical characters; that is, there were several (up to 5) spathes, orange-red fruits, and an agreement in the diagnostic features of the flowers and

fruits.[10] Karsten did not write a travelog of the Quindío; in fact, his technical description of the wax palm of the eastern slope, which bears the specific name, *quindiuense*, is set down in seven lines—three in Latin and four in German. Perhaps he did not expend more words on this species since it was perfectly clear to him that its characters were unlike much of Humboldt's description of *C. andicola* with its violet-colored fruits, single spathe, and bulged trunk.

Since a name has been proposed for the two species on either slope of the Quindío, it would seem perfectly simple to adopt these and throw Humboldt's name away. But such procedure is not in accordance with scientific rules of nomenclature. It seems a pity to have to admit that, after 135 years, no one knows just what Humboldt's *C. andicola* really is and yet the confusion is easily explained. Many persons, some of them able botanists, have traveled the Quindío since Humboldt's time, and it is natural for them to have assumed that *C. andicola* is a firmly established name for a well-understood species; certainly the type locality is for the palm on the eastern slope. It must be recalled that our information concerning many kinds of plants, including palms, comes from diverse sources, representing what has been gleaned by many individuals, often at the cost of tremendous effort and untold hardships. It is not surprising that conflicting statements, several names for the same plant, and incomplete data sometimes result. It must also be borne in mind that it was mainly due to the efforts of European botanists—Humboldt, Martius, Karsten, Spruce, and others—of the nineteenth century that the rich flora of South America was made known. The study of palms, in particular, is attended with certain special difficulties. They often grow in places which are quite uninhabited and where travel is not easy; the flowering and fruiting branches may be quite inaccessible high up on a tall, sometimes spiny stem, and observations from below are likely to be inaccurate; most palms bloom briefly each year—some only once before they die; it is definitely out of the question for a collector to be at all the palm localities at the proper time to obtain all the data necessary to a complete understanding of each species; moreover, incidental palm discoveries are frequently made while exploring for other plants. Then, too, it is scientifically impossible to make an adequate disposition of palm genera and species merely from the study of herbarium specimens or of individual plants introduced into gardens far removed from their native home. The unusual character of the wax palms suggests that they are particularly deserving of special investigation.

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[10] Karsten published these species under his new genus *Klopstockia*, probably named in honor of the German poet, Friedrich Gottlieb Klopstock.

But to return to Karsten. Each of the three new species which he described proves to be interesting in a special way. One handsome species, now rather well known, which he first saw near Caracas in northern Venezuela, represents today the eastward limit of the wax palms. This species, *ceriferum*, has a wide distribution, ranging from Caracas to the Santa Marta region in northern Colombia and extending on down the Colombian Andes for a considerable distance. It compares favorably to the Quindío wax palm in height since the reports of various observers agree with Karsten's statement that it is about 200 feet tall and likewise has a white trunk, conspicuously marked by the leaf-scars, which are 4 to 6 inches apart. Karsten first found it at 5,000 feet elevation but states that it occurs about 100 feet lower and extends up to an altitude of 8,200 feet. Karsten's drawing (pl. 4, right) illustrates this species. It is a slender palm; Karsten gives its diameter as about 1 foot. The crown is rather sparse, consisting of only 8 to 12 featherlike leaves, bright green on the upper surface, silvery beneath, and as much as 15 feet long. The coral-red fruits are about the size of a hazelnut. Rather recently, Burret, of Berlin-Dahlem, described a new species, *schultzei*, from the region of Santa Marta; its trunk is 200 feet tall but only 8 inches in diameter (Notizblatt, 1929). Such a slender trunk for so great a height is nothing short of astounding. Otherwise, it does not seem to be clearly distinguishable from Karsten's *ceriferum*.

The world's record for the highest altitude at which palms grow must be accredited to Karsten's species, *utile*, which has already been referred to as growing near the Volcan Chiles, on the boundary between Colombia and Ecuador, at 13,450 feet above sea level. Its height of 40 to 50 feet is not impressive, but it is the one species of wax palm which may be considered as truly alpine, thus emphasizing the fact that the wax palms defy the usual rules of plant growth and distribution. Karsten found that bears climb the smaller of these palm trees (not exceeding 25 feet) in order to eat the leaves (evidently the bud or "cabbage"). This report is obviously authentic but it certainly taxes credulity; one hardly associates bears with palms. Karsten relates that the leaves of this and other wax palms are used in church processions and that their very flexible leaves are especially suitable for weaving into hats. An interesting feature of the leaves of this species is that the individual leaf divisions or segments are not evenly spaced but arranged in groups of two, three, or four on the length of the midrib (rachis).

Karsten's third species has the same type of leaf, which explains its specific name, *interruptum*. This palm, from 100 to 120 feet tall, is able to grow in a warm climate, since it extends down to 3,930 feet

above sea level. Karsten failed to give the exact type locality, although he definitely placed it in the North Andean region.

Two years ago, Mrs. Ynez Mexia informed me that she was about to make a trip to western South America to secure specimens for the Bureau of Plant Exploration and Introduction of the United States Department of Agriculture and offered to collect some palm material for me, if at all possible. It then seemed probable that her route would take her into the Quindío region. I explained the methods of collecting palm specimens, and supplied her with information concerning the location of the wax palms, as well as with an outline chart especially devised to cover the wax palms. Unfortunately, she did not reach the Quindío Pass, but she obtained some excellent wax palm material in Ecuador and made careful records on the charts. The collection included an interesting species having tufted leaf segments, 4 to 5 spathes, and a bulged trunk; it grew near the Volcan Chiles "In a dense forest on a precipitous mountain side at 9,842 feet, on the road from Moldanado to Tulcan, Province of Carchi, Ecuador" and is identifiable as *ventricosum*, a recently described species (Notizblatt, 1929). Burret himself questions whether his species is really distinct from Karsten's *utile*, the difficulty being that Karsten's description makes no mention of the bulged trunk. Perhaps this is the ventricose species Spruce saw in Ecuador in 1860 and which he referred to as *C. andicola* (Notes of a Botanist, 1908).

No account of the beauty and unusual character of the wax palms would be complete without some reference to a massive wax palm which Franz Engel discovered and which is today as much surrounded with mystery, music, and poetry as it was when Engel described it in 1865. Engel saw but three individual palms, one tall and two smaller ones, in the Province of Tachira, near the Uribante River in western Venezuela. It is found at 6,000 to 8,000 feet above sea level in deep, shady woods, towering above the other trees. He describes it as a "magnificent palm", from 150 to 200 feet tall; the trunk is 2 feet through, and the leaves are 25 to 30 feet in length— the largest diameter and the longest leaves of all the wax palms. The natives told Engel that it was customary to fell the trees to secure the leaves for the making of straw hats and that it might be difficult to locate specimens. After an arduous 3-day search, only three palms were discovered. Engel was overjoyed to come upon them at last but expressed the fear that perhaps he was destined to be the only botanist to see them, while consoling himself with the thought that the vast unexplored forests of the Cordilleras might contain many more palms of this species. Perhaps it has actually become extinct, since no one has added a single bit of information

concerning it in the intervening 70 years; perhaps it only awaits rediscovery. Inasmuch as this palm secretes resinous wax just under the surface rather than on the outside of the trunk, and because of certain other botanical features, Engel placed it in a new genus, *Beethovenia* (Linnaea, pp. 677–680, 1865). This name is now retained as its specific name in the genus *Ceroxylon*.

Engel becomes most eloquent in explaining his reasons for naming this genus for the musician, Beethoven. He tells of the emotion which overcame him when he finally beheld the "sublime spectacle" of these palms. "When the exalted voices and symphonies whisper down to the listening soul from the crowns of the palms, making one forget all privations and physical sufferings", this experience, writes Engel, is akin to the spiritual rapture evoked by the music of the great master, which has the power to transport the soul beyond the material realm. He asks if it is not, then, permissible to name such a noble palm for the immortal composer.

Wax palms have only recently (1929) been described from Peru by Burret. None of these species exceed 40 feet in height and they do not appear to be as interesting as those farther north, although they grow at high altitudes (5,900 to 9,675 feet). There are specimens in the United States National Herbarium collected by Dr. O. F. Cook of the Bureau of Plant Industry, United States Department of Agriculture, on one of his expeditions to Peru (1915). Whether the wax palms extend into Bolivia remains to be discovered.

Few of us, indeed, will have the good fortune of seeing the wax palms in their native home. So far, attempts to introduce the Quindío palm into cultivation have been mainly confined to Europe; these have met with failure. No region is known in Europe which shows a climate comparable to that of the high Andes. But there is every reason to believe that most of the species of wax palms, even the magnificent Quindío species, could be grown in certain portions of the United States. To be sure, the warm subtropical regions of this country are undoubtedly far too hot in summer, and the high altitudes of our mountain regions are far too cold in winter. However, a relatively narrow strip, only a few miles wide, along the Pacific coast of the United States from the vicinity of Grays Harbor, Wash.,[11] to San Diego, Calif., has a climate remarkably similar to that of the high Andes between 6,000 and 12,000 feet altitude. The summers are very cool, and the winter climate is unusually warm for these latitudes (32°30′ to 47° N.). Dr. Walter T. Swingle, of the Bureau of Plant Industry, United States Department of Agriculture, who predicted the success of choice Old

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[11] The U. S. Weather Bureau records are from Lone Tree, Wash., on the northern shore of the entrance to Grays Harbor.

World varieties of the date palm (*Phoenix dactylifera*) in the south-western United States in advance of their being tried out,[12] informs me that probably no other region in the North Temperate Zone so nearly parallels the cool climate of the Cordilleras as does this Pacific coastal strip of our country.

Fortunately the climate of the Cordilleras of Venezuela, Colombia, and Ecuador—the very regions where the most beautiful wax palms grow—has been especially studied by the well-known authority on regional meteorology, Julius Hann. A comparison of climatologic data from four locations in the Andes given by him with equally authentic data for seven stations on the Pacific coast thermal strip is set down in the table on the following page.

A detailed discussion of the figures given in table 1 is beyond the scope of this article. However, the only important disparity is in the greater difference between the mean temperature of the hottest and coldest months on the Pacific coast as compared with those of the Andean stations. It should be recalled that wax palms are accustomed to endure, apparently without injury, temperatures only a few degrees above the freezing point. According to Hann's rule, the temperature of the "tierra templada" and "tierra fria" zones of the Cordilleras from Venezuela to Ecuador decreases about 1° F. for every 337.5 feet ascent; or, roughly, 3° F. for each 1,000 feet. André recorded an early morning temperature of 2° C. (35.6° F.) at Las Cruces in March; yet March is one of the hottest months of the Quindío region. The temperature at the upper limit of the Quindío palm, higher up the mountain, would, by Hann's rule, have been only one-sixth of a degree (0.164° C.) above freezing; at the Volcan Chiles, where *utile* grows, it would have been −5.77° C. (21.6° F.) at that time. On the Pacific coast from San Francisco to San Diego, where there is almost no variation in altitude, the temperatures increase, roughly, 1° F. for every 55 miles going south; or, in other words, moving northward 165 miles along the Pacific coast of California would correspond to an increase of 1,000 feet in altitude in the Andes.

The length of day varies but little between summer and winter near the Equator but does vary decidedly at latitudes 30° to 47° north of the Equator in California and Washington, where the summer days are longer than in the Quindío Pass region. However, frequent showers in Washington, almost daily dense fogs in San Francisco, and the "velo", or high fog, of San Diego all cut down the hours of effective sunshine during the long summer days and tend to obscure or even obliterate the difference in length of the summer

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[12] Swingle, W. T., The date palm and its utilization in the southwestern states. U. S. Dept. Agr., Bur. Plant Indus. Bull. 53, 1904.

TABLE 1.—*Comparison of climatologic data for Andean stations in South America with stations on the Pacific coast of the United States*

	Years recorded	Latitude	Altitude (feet)	Mean annual temperature		Mean temperature hottest month			Mean temperature coldest month			Difference between mean temperature hottest and coldest months	
				°C.	°F.	°C.	°F.	Month	°C.	°F.	Month	°C.	°F.
Tovar, Venezuela		10°26' N	6,283 (1,915 m)	14.4	57.9	15.3	59.5	April	12.5	54.5	January	2.8	5.0
Bogota, Colombia		4°35' N	8,727 (2,660 m)	14.4	57.9	14.8	58.6	March, April	13.8	56.8	July	1.0	1.8
Quito, Ecuador		0°14' S	9,350 (2,850 m)	13.5	56.3	13.7	56.7	December, January	13.4	56.1	July	.3	.5
Antisana, Ecuador		0°21' S	13,320 (4,060 m)	4.9	40.8	6.2	43.2	January	3.0	37.4	July, August	3.2	5.8
Lone Tree, Wash	12	46°56' N	9	10.0	50.1	14.9	58.8	August	4.9	40.8	January	10.0	18.0
Port Orford, Oreg	22	42°45' N	24	11.1	52.0	15.1	59.2	do	7.7	45.9	do	7.4	13.3
Eureka, Calif	44	40°47' N	62	10.9	51.6	13.5	56.3	do	8.3	47.0	do	5.2	9.3
San Francisco, Calif	60	37°48' N	155	13.4	56.2	16.3	61.3	September	8.9	49.0	do	6.3	11.4
Monterey, Calif	44	36°36' N	15	13.7	56.7	16.7	62.1	August	10.2	50.3	do	6.5	11.8
Santa Monica, Calif	14	34°5'	110	15.3	59.5	19.1	66.4	do	11.5	52.8	do	7.6	13.6
San Diego, Calif	59	32°47' N	87	16.2	61.2	20.4	68.8	do	12.6	54.7	do	7.8	14.1

¹ Taken from Hann, J., Handbuch der Klimatologie. ed. 2, vol. 2, 1897; McAdie, A. G., Climatology of California, Bull. L, Weather Bureau, U. S. Dept. Agr., 1903; Martin, R. J., and Corbin, E., Climatic summary of the United States, secs. 1, 3, 15, 17, 18, 19, 1932-36.

day that should normally occur between regions near the Equator and those lying far to the north in the Pacific coastal strip. That fogs and showers are not injurious to wax palms is proved by the fact that all accounts of the Quindío, Santa Marta, and other wax palm regions tell of the heavy fogs and frequent rainfall.

There is, then, every indication, from the foregoing data, that the various species of wax palms could be introduced and acclimatized at those localities along the Pacific coast thermal strip which most nearly parallel the climatic conditions characteristic of the Andean habitat of each species: *ceriferum* at San Diego or Santa Monica; *quindiuense* and possibly *ferrugineum* at Golden Gate Park, San Francisco, Monterey, or even at Eureka; while *utile* might do well at Eureka, or even in Oregon and Washington.[13] Other Andean plants are at the present time growing successfully in Golden Gate Park. As is the case with practically all species of palms, the wax palms would need to be carefully nurtured during their early years.

It is to be hoped that this article will not only arouse interest in the study of the remarkable wax palms of South America but also lead to their successful introduction into California and a few favored regions on the coast of Oregon and Washington.

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[13] J. Harrison Wright, of Riverside, Calif., had a young wax palm, thought to be *C. andicola,* growing outdoors from 1909 to 1917. He writes me that it was vigorous and thriving and then suddenly died, apparently because of the unusual hot weather of that year. The climate of Riverside, where subtropical and some tropical palms do well, does not indicate success in the introduction of wax palms of the high Andean regions, although some species of warmer habitat might prosper there. Mr. Wright also reports another specimen growing nearer the coast, which is still very small and without a trunk.

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Maps and other drawings prepared by Leta Hughey.

THE WAX PALM ON THE EASTERN SLOPE OF THE QUINDÍO PASS.
Ceroxylon andicola Humb. and Bonpl.   After André (1878, p. 223).

PLATE 2
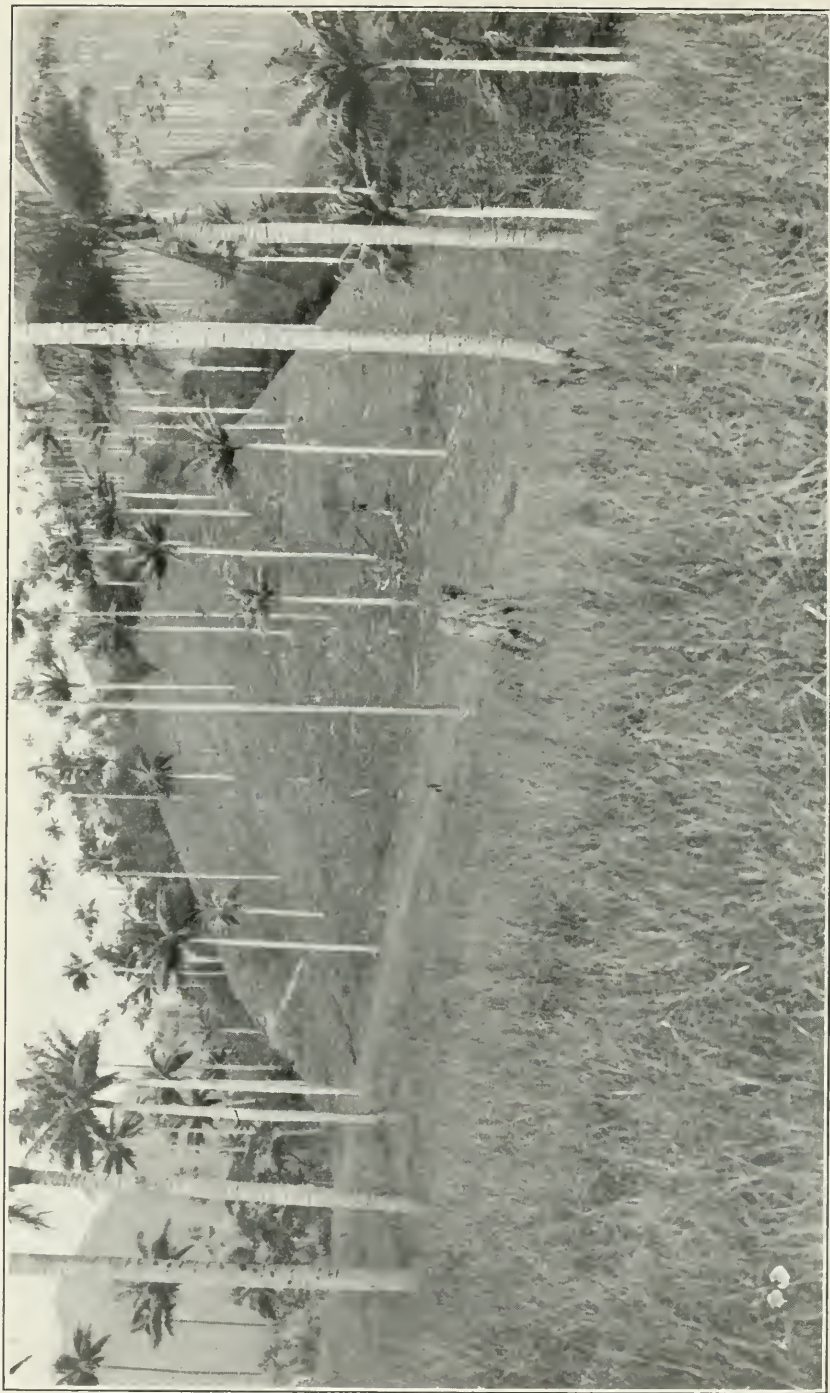
WAX PALMS ON THE WESTERN SLOPE OF THE QUINDÍO PASS.

Ceroxylon ferrugineum André. Photograph taken by E. P. Killip near Salento, August 1922

PLATE 3

WAX PALMS ON THE EASTERN SLOPE OF THE QUINDÍO PASS.

Ceroxylon quindiuense (Karst.) Wendl. Photograph taken by E. P. Killip near La Ceja, August 1922. From Smithsonian Scientific Series, vol. 11, 1931.

PLATE 4

TWO OF KARSTEN'S WAX PALM SPECIES.

Ceroxylon quindiuense (Karst.) Wendl. (left) and *Ceroxylon ceriferum* (Karst.) Burret (right).   After Karsten
(1858, pl. 1).

SIGNIFICANCE OF SHELL STRUCTURE IN DIATOMS

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[With 19 plates]

"MAXIMIS IN MINIMIS"

In this day of rapid industrial change and advancement, of new and novel ideas, and of strange and futuristic tendencies in design, when it is a question how quickly the next idea will become obsolete, and when there is much discussion as to whether in a few years we shall be living in houses of steel, paper, or glass, it is interesting to take note of a large group of small plants that have been living for 30,000,000 years or more in glass houses and still find this a very successful type of abode, literally building about themselves walls of glass and frequently elaborating these walls in beautifully sculptured and highly ornamental architectural designs. These are the diatoms, of which there are more than 10,000 different kinds. They are all single-celled or colonial plants.

If we were to adopt this kind of structural material, everyone's affairs would be even more subject to discussion than they are at present; curtain and venetian-blind manufacture would constitute one of our major industries. But for the diatom, as for all other plants, exposure to the light is a necessity. They have the advantage of being so small that, with few exceptions, they cannot be seen with the unaided eye; hence, though they have lived and continue to live this transparent existence all about us, in every damp spot, every roadside pool, river, lake, and ocean—resting or crawling on the bottom, attached to submerged objects, and floating suspended in the water—in unbelievable numbers, it is practically only within the last 100 years that we have become acquainted with them at all. Few diatoms are larger than 1 millimeter, that is, one twenty-fifth of an inch in diameter, and most frequently they are less than one-tenth that size, or one two-hundred-and-fiftieth of an inch. The details of their structure are often exceedingly minute, comprising the most delicate and perfect sculpturing in glass, or, to be exact, in silica.

Diatoms extract this silica from the water, where it is dissolved in very small amounts, and deposit it in the membranes of their cell walls to form the microscopic boxlike encasements or shells that protect and support the living cells.

The most striking features of a diatom, as seen under the microscope, are the symmetry of its form and the intricacy and perfection of structure of so minute an organism; nor is this purely accidental, for nature is a most careful and efficient designer. Not only is this structure intrinsically beautiful and interesting, but it is of great significance in several respects.

Of course, the structure is primarily of fundamental importance to the diatom itself; secondly, it is of importance in the general economy of nature, insofar as this concerns the diatom; and thirdly, and incidentally, in the possession of properties different from those of any other material, it is of wide general importance to mankind, as we shall hope to see. It will be well to consider these three important functions of diatom shell structure in the above order.

1. IMPORTANCE OF SHELL STRUCTURE TO THE DIATOM

Obviously, no active living organism could for long survive in a single solid glass shell, for it could neither grow nor reproduce. The rigid and inflexible nature of such a substance as silica necessitates some special arrangement whereby growth and reproduction of the cell may be accomplished, and nature has provided for this by designing the cell wall or shell of the diatom in two parts like a box, with a box and a lid, and a flange or girdle on each part to overlap or telescope them together, a unique plan that is found in no other organism. In fact the whole life of the diatom seems so ordered as to be fitted to the nature of this material; and the structure of the silica shell, in turn, gives constant evidence of its adaptability to facilitation of the life processes of the cell.

In growth, for instance, a cup- or box-shaped shell of so inelastic a substance cannot expand in diameter, or length and breadth, as can the ordinary plant and animal cell walls composed of more flexible materials such as pectin, cellulose, protein, or other organic material. The cell can grow only in depth, by a building onto of the edges of the shell or girdle and a gradual slipping apart of the telescoped shells, one from the other, as seen in plate 4. Thus the cell can grow only by extension in one direction, or expansion in one dimension instead of three, a phenomenon rather peculiar to the diatom.

In reproduction, when the cell has grown and matured as above described, the protoplast within divides in two, and new shells are deposited upon adjacent walls of the two new protoplasts thus

formed, lying back to back as in plate 4. Each new shell, together with one of the original parent shells, and the protoplast lying within forms thus a new cell. Subsequently, the old girdle slips off and the two new cells appear as new individuals to repeat the process. In this common and well-known method of vegetative reproduction, the new shells being formed within, one of them is in general necessarily smaller each time division takes place. This process continued indefinitely would result in some of the cells becoming gradually smaller to the point of extinction were it not for the intervention of another type of reproduction peculiar to the diatoms, known as auxosporial reproduction, in which rejuvenation of the size of the cell is achieved.

In this process, in various ways in the different species, the protoplast expands, or two cells unite and the protoplast resulting from this union expands, and the old shells are thrown off entirely. The large gelatinous structure thus produced is known as an auxospore, which after a time forms upon its outer membranous wall two entirely new shells of larger size, and a new individual of large size is produced. This innovation is necessitated by the rigid and inflexible nature of the silica shells.

The unique method of producing new shells within the old in the ordinary process of vegetative reproduction assures that the offspring will be, in outline at least, an exact copy of the parent.

The girdle which plays so important a part in the structure, growth, and reproduction of the cell, presents a number of nice adaptations for its particular function. It must be such a structure as will hold the two shells firmly together and prevent collapse of the cell at such a point of frailty and yet permit of ready division of the cell at the midregion for purposes of reproduction of the species. The girdle provides satisfactorily for this, surrounding the cell at this point, clasping the shells and holding them tightly together in position, and yet it is capable of being thrown off at time of reproduction (and without much loss of material) to allow division of the cell and subsequent pushing apart of the two newly formed cells. In providing this arrangement, nature has in many cases designed the girdle not as a complete hoop or ring, which would be inflexible, but rather as a band open on one side to permit it to be thrown off with ease at the proper time. The same principle has been used by man for the expansible rings formerly used to hold some types of automobile tires in place on the wheel, for the little expansible rings that hold lenses in their mounts, and for the ring clips that hold some types of fruit jar covers in place. When this girdle band consists, as is the case in many species of diatoms, not of one ring alone but of several or numerous adjacent and interlocking ones interpolated from

time to time as the cell grows, it is clear that these would be weakened if the open side of each ring came at the same place as the one next to it, making a continous cut across the whole series of rings; so nature avoids such a weakness by ordering that the opening of each ring shall come at a different place in the series, like the mortar joints of brick in a wall, no two being in line with each other. Nor is this enough to satisfy the niceties of nature, for frequently the open ends of these girdle bands are especially dovetailed and grooved to fit into each other and lock together, and the edges of the girdle band or ring are serrate or notched to fit in corresponding notches in the rings adjacent to it (pl. 2). All of this adds, not only to the strength, but also to the beauty of the diatoms in varying their patterns. And when any particular feature of design of an object adds to its strength, it usually means an economy in the amount of material necessary for its construction, a matter of importance in the efficiency of nature as will be noted later.

To breathe and obtain food substances for growth and reproduction all cells must be able to absorb material in solution through their cell walls, but as silica is an impermeable material, special provision must be made in the diatoms for such absorption. This absorption is made possible by numerous pores through the shells, variously arranged in the different species, frequently forming beautiful patterns on the shells. These porous spaces are covered with a semipermeable membrane, composed of some pectic substance, which permits the interchange of liquids and soluble food materials between the exterior and the interior of the cell.

These porous spaces through the silica shell naturally lighten and weaken the wall, and this weakness is overcome by various means in different types of diatoms. Sometimes, in the more plain and simple types of shells, there is merely a thickening of the silica between the porous spaces. Seldom is the shell surface of the diatom flat; instead there is usually some degree of curvature to the surface, often very slight, but in many cases the shell is highly concave or convex, and this curvature in itself serves to strengthen the shell, just as dome-shaped ceilings over large rooms can be supported more easily and rigidly than flat ones. The flexible nature of the protoplast and the conditions of tension and of internal and external pressure of the cell as the shells are being formed control these forms in the various species. In many other diatoms—those with particularly flat shells such as Arachnoidiscus, or others with large openly porous shells such as Isthmia and many Biddulphias—internal ribs or cross walls are present to add strength to the shell, just as ribs on large steel doors and gratings, inside of pianos, and in the bottoms of boats are used to increase strength instead of building a heavier solid structure.

In many diatoms an alternate raising and lowering, or undulation, of the surface gives strength and rigidity, just as is accomplished by the corrugated surface of the galvanized sheet iron commonly used for roofing, sides of garages, and factory buildings. (See pls. 14, 15, and 16.)

In still another large series of rather more elaborate and complex diatom shells, the shell surface consists not of one, but of two very porous layers one above the other with very thin upright joining walls between them forming small hexagonal chambers, into each of which one pore of the external and one of the internal wall open, forming thus, except for the previously mentioned permeable membranous covering, a continuous passage through from the outside to the inside, and yet giving a maximum degree of strength and great rigidity to a highly porous surface by the use of a minimum amount of material (pl. 3). In many of the larger-celled diatoms, in which the mass of the cell is great in proportion to the material substance and strength of the shell, the shells tend to assume the spherical and tubular shapes—shapes much used by man for tanks, pipes, and containers because these shapes are intrinsically strong and afford the enclosure of a large amount of space with a minimum amount of structural material.

The fraility of this exceedingly delicate shell necessitates in many species special types of strengthening and supporting structures, such as internal cross walls or septae, thickened solid silica bars, and sometimes even internal plates or chambers, or secondary and inner shells. All of these features, together with the natural trends of variation, tend to multiply greatly the types of structure and form found in the diatoms, so that they include every conceivable geometrical design and variation and sometimes even almost unexplainable shapes.

Having seen how important the structure of the shell is to the diatom cell itself, if we turn now to consider how the structure relates to the kind of place in which a certain species may live, we find again an amazingly beautiful series of adaptations to fit the cell to life in its particular habitat. Thus diatoms that grow attached to other submerged plants or objects may take long needle-shaped forms, allowing for the attachment of great numbers of their ends, and their exposure of a maximum amount of surface to the water. Another arrangement for this same purpose is found in fan-shaped cells set in fan-shaped colonies attached by their small ends, and in the growth of long filaments with endwise attachment. Large free-living cells must have walls of heavier silica and often more internal cross walls. Since silica is twice as heavy as water, it is necessary that diatoms which live continuously floating in the open

ocean have shells as lightly silicified as possible, and in order that they may have the necessary strength they are usually very small, round, or tubular in shape, or with numerous cross walls (pls. 2 and 5). Often, too, long spines increase the amount of surface to keep them afloat.

2. IMPORTANCE OF DIATOM SHELL STRUCTURE IN THE GENERAL ECONOMY OF NATURE

With all these various types of structure, and with their small but rugged shells which because of their minuteness are capable of rapid reproduction and may easily be transported hither and yon, it will be realized how readily diatoms can be scattered throughout the oceans and utilize to the fullest extent the dissolved mineral substance present.

These types of structure provide simultaneously for great strength with correlated economy in the use of silica, which because of its high degree of insolubility in water (only a few parts per million in most natural waters) is a precious material to the diatoms and is often completely used up by them during the height of their growing season. The porous and chambered type of wall structure mentioned heretofore as common in so many of the diatoms permits of the walls being of exceeding thinness, in most cases beyond the possibility of convenient measurement, and often as thin as two one-hundred-thousandths of an inch, yet of great rigidity in order to avoid collapse of the cell. It is advantageous in the economy of nature that a great abundance of diatoms should be produced in all waters to afford a food supply for the animals living there, even with the small amount of silica available. It is likewise desirable in the economy of nature that these diatoms should use sparingly of so rare a substance as the slightly soluble silica, so that the available supply will suffice to produce the greatest possible number of them. This could not be better accomplished than by the nicety of adaptation exhibited by the very strong and yet very delicate structure of their shells. Studies of this subject have been made in our laboratory and will be published more extensively in a later paper.

Man uses the same methods in the construction of long bridges, deriving great strength simultaneously with lightness of weight and a minimum use of costly material by designing long open-work girders and trusses. Another example of achievement of great strength through the form of structure with even a very frail material is the use of the common corrugated paper box for shipping surprisingly heavy and extremely fragile materials.

Another well-adjusted arrangement in the economy of nature is the production of light-weight shells adapted for buoyancy of

diatoms that live habitually floating in the open sea, where, at the same time, silica is less abundant. However, those diatoms that live attached, where the continual wash of water brings to them an abundant supply of the necessary substances for growth, can produce either heavier shells or a very luxurious growth within a small area, and along the bottom, nearer the source of silica, live the heavier, larger diatoms with a massive type of shell structure, indicating an ample supply of structural material. (Pls. 5 and 6.)

Why diatoms are so infinitely multiplied and diversified to all conceivable shapes and patterns, when a few types of shell structure could probably fulfill their purposes and needs, is an evolutionary and philosophical question which applies to other life forms as well and which has not yet been answered. One might as well inquire why man has not deliberately planned a model house incorporating all practical features of comfort and convenience, and having once designed this model house, busied himself with building a world full of these houses for all men to live in; but many different individuals develop as many diverse ideas of structure and design.

It is interesting to see in a group of such minute forms as the diatoms so perfect an application of the same principles and devices as are found in larger forms and as have been made use of in many ways in the works of man. Throughout the group of diatoms, their shells seem to embody the elements of fine structural engineering, together with principles of architectural design adapting them to their types of abode and to the necessities of their various modes of existence. All features of their shell designs seem to center about and be controlled by these purposes, which contribute largely to the great diversity and beauty of design and incidentally to their wide industrial application, as we shall see.

The whole history of civilization, of man's exploitation of material and subjection and control of energy resources in his attempt to establish his domain over nature, has shown a steady trend toward an understanding and manipulation of the finer and ever finer forces and conditions of nature. So it is that small things which have seemed of little or no importance have come one by one to take prominent places on the stage of human interest, and the oft-repeated question, "What is it good for?" promises eventually to be answered for every natural substance.

The renowned biologist Lamarck has said (Philosophie Zoologique) : "The most important discoveries of the laws, methods, and progress of nature have nearly always sprung from the examination of the smallest objects which she contains, and from apparently the most insignificant enquiries." The late Theobald Smith is quoted (Simon Henry Gage, Science, vol. 84, no. 2171, Aug. 7, 1936, p.

121) as having said: "We who have dealt with the finitely small living things have, perhaps, as much a sense of the highly complex, unfathomable, the eternally elusive in the universe as do those who look for the outer boundaries of space. Each group contributes a different story of the same final significance."

3. TECHNICAL AND INDUSTRIAL SIGNIFICANCE OF DIATOM SHELL STRUCTURE

It will be readily perceived why these varied forms of delicate but strong, hollow, boxlike shells, composed of a resistant and inactive material, in the form of thin walls and with a tremendous amount of exposed surface, may have many advantages for industrial uses because of these peculiar qualities. Their small size, for instance, together with their great porosity, makes it possible for them to be closely compacted and yet to possess an astonishing amount of pore space. This porosity renders compact masses of diatomaceous earth, composed almost wholly of the shells of diatoms, exceedingly light in weight, sometimes only one-sixth to one-ninth as heavy as water, or as low as 8 pounds to the cubic foot, although silica, of which it is composed, weighs twice as much as water, or 130 pounds to the cubic foot. The remainder represents air space, amounting sometimes to as much as nine times the actual amount of shell substance present. (See pls. 8 and 9.)

The very fine and precise structure of diatoms early found utility in scientific work in the recognition of its excellence as an object for testing the quality of high-power microscope lenses. Among the diatoms a sufficient range in size permitted the selection of various species adapted for the testing of each different power of lens, the structure in each case being on the border line of visibility for the particular lens to be tested, so that a lens of good quality would resolve it while one of poor quality would not. Nothing has subsequently proved more suitable for this purpose.

Lately a professor of the physics department of the University of Illinois, seeking a fine, open mesh-work support or grid for the very delicate metallic films only one to a few atoms thick which he was able to produce and which he intended to bombard with other atoms in research studies on the structure of atoms, looked naturally to the fine porous shell of the diatom as the thing which might most readily meet his requirements. What was needed was a fine sievelike screen to support the film and yet provide free, open space for the unhampered passage of a stream of atoms directed against the film. In answer to this rather unique request for the cooperation of the diatomist, it was possible for our laboratory to select for him such types of diatoms as would conform to his specifications. Thus it is impos-

sible to say at what moment, or in what connection, the study of the structure of these minute plant forms may be turned to practical use.

The luxuries and comforts of modern life and the innumerable appliances devised through the ingenuity of man to secure and increase them, have created such a demand for raw materials for his uses, from the most common and abundant substances to the rarest and most unusual elements, that scarcely any material escapes his vigilant eye. Mankind has developed a new realization of the potentialities of materials and a new interest in researches upon their properties. Thus whenever any kind of substance is found to occur in considerable quantity, its possibilities are recognized and investigated, and sooner or later it is likely to find one or many uses of human importance. Frequently this usefulness is based upon some apparently insignificant or unique property of the material.

Such has been the history of the use of diatomaceous earth, which 30 years ago was known to only an occasional scientist and to but a very small group of industrialists, but which today has been heard of by most people and has found its application in some phase of almost every industry, affecting every angle of our daily lives. Comparatively few people yet know what it is, and fewer still have inquired into the full significance of its unusual properties.

Diatomaceous earth is typically a fine whitish earth composed largely, often practically purely, of the fossil remains, or shells, of diatoms, accumulating by slow deposition in quiet waters over long periods of time, the resulting deposits being exposed through subsequent rising or upheaval of the land. Luxuriant growth of these little plants in undisturbed waters, free from inwash of sand or other foreign matter, has resulted in the formation of many large deposits of very pure diatomaceous earth (pl. 7). These deposits are to be found widely scattered and over vast areas of the earth's surface previously covered by oceans, lakes, and other bodies of water in ages past. Quick decomposition of organic matter and leaching out of soluble materials has left almost nothing save the very insoluble and highly indestructible shells of the diatoms, insoluble because they consist of silica and comparatively indestructible because they are so small that they easily slip in among other particles without being crushed.

The very fine porous structure of these shells and their characteristic shape give to diatomaceous earth certain peculiar properties which make it valuable. Chief among these are high porosity, extreme lightness of weight, and great amount of surface with comparatively small amount of actual material. If we were to fill a room from floor to ceiling with tiny cardboard boxes of various shapes we should have an arrangement homologous to diatomaceous earth.

The whole bulk would be very light in weight, and would really consist of very little actual substance, and the interspaces between and within the boxes, representing porosity, would be a very considerable part of the whole volume. If, further, these little cardboard boxes were perforated with countless pores, they would offer a still greater amount of surface and still less actual material, and in this respect they would still more nearly resemble the diatom shells in a mass of diatomaceous earth.

We can get the best conception of the qualities of diatomaceous earth upon which its value rests, if we think of it in terms such as these: The delicate shells of the diatoms which compose the earth represent surface and area, with relatively great quantities of enclosed space; whereas sand or other solid particles of silica, the same substance, represent volume or mass, and consequently much greater weight in proportion, and much less surface area and pore space (pl. 9). Consequently, the latter particles fall rapidly through air or water because they are heavy; also they have less surface for the absorption of heat, and less pore space for the absorption of fluid.

In fact there is no other substance which can take the place of diatomaceous earth for many of the uses to which it is put, and there is no other organism or process capable of producing such a substance. In other words, it cannot be duplicated; the prediction may even be warranted that this is one substance man will never be able to produce synthetically or even find a suitable substitute for. Please bear in mind again that it is the size and structure alone which give it these unusual qualities, and of these it is the structure only which man cannot reproduce or imitate and which is produced by no other organism, nor found in any other natural material. Human ingenuity has been able to spin threads as fine as those of the spider, to spin such threads in as hard a material as quartz, to bore almost invisible holes through diamonds, to duplicate perfectly so delicate a structure as the honeycomb of the bee, and to grind particles as small as, or smaller than, diatoms. Man is not only able to grind such small particles, but he can make them into little spheres; but the one thing he cannot do, now, or probably ever, is to make them into little hollow boxes with porous walls of glass. This only the diatom can do, and in this it seems to have attained the ultimate of perfection.

Because of its porosity a block of diatomaceous earth, being much lighter than water, will float on the surface of a body of water until the pores fill up sufficiently for it to become waterlogged and sink. This the ancients knew, though they knew nothing of the origin of the material; furthermore, they had no microscope to tell them its

nature or the reason for this wonderful quality. However, they found the material useful and cut it in the form of bricks, which they called most appropriately "swimming bricks."

The earliest record we have for the commercial use of this material is in A. D. 532, when the Emperor Justinian, finding it impossible to carry out his plans for the construction of the great dome of the Church of St. Sophia in Constantinople because of the weight of stone to be supported on four arches over the great expanse of 107 feet, resorted to the use of diatomaceous earth, or "swimming brick." This was not so practical as it might seem, however, for the material has little strength, and when it becomes wet, it likewise becomes correspondingly heavy.

As has been seen, the lightness in weight and the porosity of the material go hand in hand. Diatomaceous earth, which weighs only about one-seventh as much as water, is also sometimes so porous as to be capable of absorbing as much as eight times the amount of actual solid diatom substance in a given volume, or, in other words, an amount of liquid equal to more than three-quarters its gross volume. This property has been made wide use of in a variety of interesting ways.

When Alfred Nobel, founder of the famous Nobel prizes, as a chemist and the inventor of dynamite, was casting about for a highly absorbent material to carry the dangerous nitroglycerine in quantities of high potency and yet in a form that could be handled with comparative safety, he turned in 1868 to diatomaceous earth. This was one of the early important applications of the material. When this original dynamite was used as powder in a gun, the explosive force caused the extremely hard diatom shells to cut and score the inside of the gun barrel. Since that time wood meal, a more expensive, equally absorptive, but slightly more suitable material has been substituted for the earth in this use.

More lately the earth has been used for packing about the glass bottles or carboys in which dangerous and corrosive liquids, such as sulphuric acid, are shipped. If during transportation the container should leak, or break, the acid is slowly absorbed into the highly porous earth and remains as a relatively solid and dry mass, arriving at its destination with no damage done. The siliceous earth is unaffected by the acid, and the capillary spaces of the little shells, owing to their structure, hold the acid with a tenacity which gives full assurance of protection against any damage.

Recently a Florida inventor has been developing the idea of an absorbing unit to carry fuel (gasoline) for a foolproof and perfectly safe kitchen range similar to, and fully as efficient as, the ordinary gas stove, to be used in rural communities where illuminating gas

is not available. The highly inflammable nature of kerosene and gasoline, and the danger of handling it in filling the stove, besides the difficulty of keeping it from leaking onto the outside of the tank, has resulted in countless explosions, fires, and deaths in rural communities and even in cities, where such fuel also finds considerable use. How simply this danger may be obviated by filling the tank with very porous diatomaceous earth, without greatly reducing its holding capacity for gasoline, is illustrated in this man's invention.

Tanks filled with diatomaceous earth, saturated with gasoline, will contain a volume of gasoline over three-quarters their actual outside volume. They can be put up at the factory to be sold in any grocery or hardware store, or simply to be exchanged at the price of the gasoline for tanks recently emptied, doing away with the necessity of handling the fluid at all. The tank is slipped into the stove and coupled by a simple connection to the pipe leading to the burners. Pushing the tank into the stove makes an electrical connection which lights a small electric bulb fitting into a depression in the outside of the tank. The warmth from this little light expands and volatilizes some of the gasoline, producing a pressure within the tank of 8 pounds. When this pressure is reached, a simple automatic pressure regulator breaks the electrical contact, turning off the light, and the warming and volatilization is stopped until the pressure again drops slightly and the light once more comes on. When a burner is turned on, the volatilized gas flows to the burner and is ignited. The resulting drop in pressure causes the light to turn on and drive more gasoline out of the diatomaceous earth in the tank. The whole apparatus resembles the ordinary gas stove, and the danger of handling liquid fuel is avoided, as it is to all intents and purposes in a solid state and hence cannot leak or spill out if the tank is upset or damaged.

Not only do the little shells make a good absorbent, but they are an equally good filter material, owing to the porous structure as seen in some of the photographs (pls. 13–19). In sugar refineries, if the sugar solution is run through cloth or fiber filters, the sediment soon collects on the filter surface, clogging it up and stopping the process. If a certain quantity of finely divided diatomite, consisting of the loose shells of diatoms, is dumped into the solution to serve as an aid to filtration, or technically, a "filter-aid", some of these little shells soon pile up against the cloth and their fine pores catch the sediment, then more shells fall against them and more sediment is held in these, and so on. At no time is there a thick impervious mat of sediment on the filter, but a porous mass of diatom shells and sediment intermixed, so that a continuous filter surface is being formed during the process of filtration. There is no other substance which meets the requirements for this need.

Nearly every household now-a-days has a jar of diatomite on the kitchen shelf—not, of course, so labeled, but under the name of silver polish. The material is very superior for this purpose. To clean the rust from a piece of iron, it is natural to use a file. To clean the corrosion, or silver-oxide, from a piece of fine silver, it is logical again to select a file, but a much finer file in order that it will not scratch the surface of the silver or cut away any of the precious metal. Precisely the kind and size of file that is needed in this instance is found in the finely ridged and sculptured surfaces of some of the diatoms. Two of these little "files", greatly enlarged to show their rasping surfaces, are illustrated in plate 10, and between them is a photograph of a bit of the earth containing many of these small instruments. They are fine enough to remove the tarnish, but not so fine as to remove much of the surface. For these same reasons they are suitable and widely used also in polishes for automobiles.

The form just mentioned is adapted not only for polishing, but also for use as a reinforcing or binding material in paints and plastics. The liquid plastic or paint fills the pores and the spaces between the ridges on the diatom shells, and when the material hardens, the whole mass locks together in a very tenacious texture that resists cracking. It is the same principle that is used in putting hair, fiber, or other binder in plaster, but on a much smaller scale; the intricate sculpturing on the diatom shell presents a great amount of irregular surface for the firm attachment of the matrix. Even concrete is made stronger by the incorporation of these little shells. It is a case of many small forces working together.

The same effect is obtained when diatomite is mixed with tar for roofing. The diatoms are small and mix easily, yet they bind firmly. Also, they make the tar dry and prevent its running when it becomes warm and soft in the sun, and render it less sticky; and the combination makes a firm roofing material that is resistant to cracking or checking. A homogeneous mixture of the diatomite with the tar is readily obtainable, which is easy to apply to the roof, and is at the same time very adhesive. Longer fibers are no better and are more troublesome to handle.

When the bright sun shines on an exposed hillside of very pure diatomaceous earth, the substance glares with the whiteness of new fallen snow (pl. 7), so that workmen in the neighborhood find it necessary to wear smoked glasses. The diatom shells themselves are, of course, of glasseous silica and actually transparent; the whiteness is due to complete and total reflection of the sunlight by the fine, intricate structure of the diatom shells, for, as is well known, sunlight when totally reflected and completely diffused is white. Thus we see that even the color is a product of the structure.

This brilliant whiteness proved to be cause for the sad disillusionment of a paint manufacturer who thought this quality in a material so permanent would be a fine basis for an excellent nonfading white paint. He began producing such an article with the full expectation of superceding all other white paints, that the diatomite would be cheaper than other white pigments, and that it would not be subject to oxidation and the chemical changes ordinarily affecting and discoloring paints. But when his material was applied to a building he was much surprised to learn that it gave a colorless, glazed, and varnishlike surface, transparent and with no color at all except that of the original surface on which it had been spread. When the form of the shells, which had been responsible for the white color, was modified by filling the spaces in the shells with linseed oil of nearly the same refractive property for light, and the mixture was spread out thin on a surface, the light was no longer reflected but passed through the transparent film. This is the same effect obtained as when water or oil is spread on ground glass, or when white paper is permeated with oil or paraffin, and becomes translucent.

Though this indicates that diatomite is useless to give color to paint, it should not imply that it is not a useful constituent in many paints, for it gives them a filling, hardening, and binding quality of value, and in many paints that would be otherwise brilliant and glaring, it gives a softness of luster due to the diffusion of light by the fine reflecting surfaces of the diatomite particles. To obtain a material that would give this effect by the crushing and grinding of sand or other quartz material would be a troublesome and costly process, but to obtain it by the grinding of the already frail and thin diatom shells is relatively simple and easy. Hence the delicacy of structure aids in the production of this very useful material.

It has also a quality of hardness and resistance in silica paints used for surfacing concrete and brick in damp places such as subways and tunnels.

Because of its quality of reflection and radiation of light and coincidentally of heat, a lining of bricks made of diatomaceous earth greatly increases the efficiency of a fireplace. Less of the heat goes up the chimney and more of it is thrown out into the room; also, the cheerful glow of the fire is enhanced by the background of white bricks.

No more effective material than diatomaceous earth can be found for insulating the walls of one's house to keep it warm in winter and cool in summer. Mixed with a binding material, such as asbestos fiber, it is as convenient to handle as mineral wool and is fully as efficient.

There are three typical methods of heat transmission—radiation, conduction, and convection. When the space within the wall is filled with diatomaceous earth made up of the very porous little shells of diatoms, any heat of radiation which might strike this material is immediately reflected and radiated back into the room. As there is a very small amount of contact between the separate shells where they touch each other, and as the silica itself is a very poor conductor of heat, a minimum amount of heat will pass through the wall by conduction. Most important of all, the large open air space which permits of ready transfer of heat outward by convection currents in the uninsulated wall is now partitioned into innumerable infinitesimally minute air spaces by the little porous hollow shells. Air spaces if of small dimension are the best insulation against loss of heat, and with this type of insulation a maximum amount of air space is present in the wall, and yet air currents which might carry away heat by convection are almost entirely prevented by these exceedingly small enclosures.

These same principles prevent the passage of sound through a wall; or, if fine, dry diatomite powder is dusted on the surface of a newly plastered wall in a church, auditorium, or theater it will adhere and make a finely porous and rough, though apparently smooth, surface which will stop the reflection and echoing of sound, thereby improving the acoustics. The ordinary plaster or papered wall has a hard, smooth reflecting surface for the sound waves falling upon it and produces echoes which interfere and reverberate. If the wall is hollow, it increases the trouble by acting as a sounding box. Hanging soft draperies in front of the walls is costly, troublesome, and not always desirable; they soon become dusty and are not always effective in stopping echoes. The sharp edges, pores, and corners of the diatom shells, however, catch the sound waves, breaking them up and preventing their escape back into the room as a definite interfering tone. (See pl. 12.)

It is interesting to note that the diatom shells of powdered diatomaceous earth will not pass through a sieve with any degree of ease, or scarcely even at all. We commonly think of anything small, fine, and light as passing readily through a sieve, and in most of our experience with ordinary fine powders this is true; but the diatoms with shells of irregular size and shape, with their horns, spines, and sculptured surfaces, become all tangled up, wedged in, and locked together into little fluffy balls that grow like children's snowballs, picking up more and more of the shells as they roll over the surface of the sieve, and defying all effort to break them up or make them pass through. This characteristic of diatomite is industrially signifi-

cant because it necessitates the grading of the material by air flotation rather than by sifting.

It is probably not widely known that the shells of diatoms can be used to stop dust explosions. These explosions have long been a serious problem in coal mines and grain elevators, flour mills, wood-planing mills, and other plants, and they have become increasingly numerous with the growth of industrial processes. Often they are very violent and do great damage. Dust explosions may occur wherever particles of a combustible dust—coal dust, textile fibers, paper pulp, soybean meal, flour, soap, cereal dust, wood meal, or other finely divided organic matter—becomes suspended in the air in a mine or manufacturing plant in considerable abundance, though perhaps not sufficiently dense as to be noticeable. Each particle is surrounded by air but is close enough to its neighbor so that when it ignites from a possible spark or flame (as, for instance, the spark created when the heel of one's shoe strikes a rock) and combines with the air around it, the heat can be absorbed by the adjacent particle, which in turn ignites, increasing the heat, which is passed on to still another, and so the combustion grows, spreading so rapidly as to become an explosion.

This all happens quicker than it takes to tell it, the explosion increasing rapidly to a peak of violence and then quickly declining in force. Such an explosion is usually localized first in some small corner of a mine. The impact of this small local explosion compresses and disturbs the air in the whole enclosed space communicating with it, raising and scattering dust from every corner and surface of the mine or room. Hence the whole place is immediately filled with clouds of combustible dust of the same nature as the first, and slightly later, but almost simultaneously with the initial explosion, there occurs throughout the whole mine or building a secondary and much more violent and destructive general explosion which does the major damage.

There are two ways to combat dust explosions: (1) By prevention—that is, by using measures to keep the air clean or free from combustible dust, by washing and spraying dusty walls, etc. This is not very satisfactory for it is difficult to keep the air clean, and one can never be sure at any particular time that the air is safely free of dust. (2) By "rock dusting", which consists of dusting all walls, ledges, and exposed places with fine diatomaceous powder. If this has been previously done, or is regularly practiced, the primary impact of a dust explosion will scatter the diatoms throughout the air, and the second and violent explosion will not occur at all. This is because of the interposition of the fine noncombustible, heat-absorbing diatom shells among the particles of combustible dust.

They are small and light and will consequently remain suspended in the air for a long time. They have a great amount of surface area for absorption of the heat of adjacent burning particles. They are poor conductors of heat and hence transmit it slowly to other nearby particles; in fact, they largely retain it.

These qualities are again due wholly to the form of the diatoms. Sand of the same material and size would not do, for it is too heavy and would not stay suspended in the air long enough. No other material can take their place in preventing dust explosions; only the delicate diatom shells meet all these requirements.

Another very different and very recent use of diatomaceous earth is in the manufacture of waterproof saltcellars. Everyone is painfully familiar with the affinity of table salt for moisture in the air. In the South, at the seashore, in fact, in any locality where the air becomes sultry, saltcellars rapidly clog. The advent of warm weather and rising humidity exacts a toll of battered knuckles, new dents in the table top, and damaged tempers, with futile efforts to dislodge the salt from the top of the shaker. Attempts to overcome the difficulty by putting rice in the shaker with the salt, keeping the shaker under a tumbler, and other such makeshifts have long proved ineffective. Whenever the thin metal cap of the usual type of saltcellar, perforated with numerous openings, is exposed to the moisture-laden air, there is sure to condense on it a thin film of moisture to which a little salt will adhere; this salt attracts more moisture, and more salt immediately sticks to the mass, rapidly clogging the small openings; then corrosion may even set in, and the whole thing becomes practically useless as a salt dispenser. The difficulty has seemed inevitable; one of those things that "just can't be helped."

Here again the structure of the diatoms proves of unique value, and only within the last year there has been placed on the market an entirely new type of salt shaker involving their use, which overcomes very simply and effectively the clogging difficulty (pl. 11). It consists merely of a small cone of diatomite, with a single hole through it, that fits in the top of the shaker under the metal screw cap which serves to hold the cone in place. How then does this simple device act to keep the salt dry and prevent the shaker from clogging, and upon what do its unusual properties depend? Everyone who has had the experience, and nearly everyone has had at some time or other, of trying to wash and dry thoroughly a tall, narrow-necked bottle, which cannot be wiped but can be dried only by allowing it to drain and the remaining moisture to evaporate, realizes how slowly the final moisture evaporates or diffuses out through such a narrow-necked structure. Just as slowly as it passes out through such an opening, so slowly, likewise, can moisture pass in

through the narrow opening in this new saltcellar, in contrast to the greater readiness with which it may circulate through the more numerous openings of the thin cap of an ordinary shaker.

Whatever moisture might enter with the air through this small opening is absorbed by the strong capillary suction of the minute pores of the diatomite and is tenaciously held by the surface tension of the very small spaces and enclosures so that it does not diffuse into the saltcellar to moisten the salt. There is no tendency for salt to adher to the dry surface of the cone, nor can the latter corrode. Thus in the wettest weather the salt flows from the shaker in a dry stream like sand through an hour glass, and its little cubical crystals bound about upon one's plate with the resiliency of golf balls.

Another application of this same principle is in the designing of an "air-conditioned" bread box, in the top of which is inserted a small plate or disk of porous diatomite. This keeps all dust and dirt out of the box, at the same time conditioning the air in the box by permitting the slow transfer of moisture in and out; this regulates the humidity without allowing a sufficiently rapid circulation of air to dry out the contents, and this degree of regulation seems sufficient to keep the air in the box in a purer condition and prevent the bread from spoiling or molding as rapidly as it is likely to do in the ordinary bread box. Again the structure of the diatom provides the qualities necessary for this purpose.

Some time after the World War a very troublesome and baffling condition developed in the alcohol industry, and executives of a large alcohol corporation spent a great deal of money over a period of several years seeking the mysterious cause of the condition. An important raw material for the production of commercial alcohol is molasses, the residuum of the sugar refineries of Cuba. This molasses is shipped in large tank steamers to Wilmington, Del., for example, where it is fermented and distilled to obtain the resulting alcohol. Strong suspicion arose that a very nefarious practice was growing up in this trade—a suspicion that some of the captains of these molasses transports were adulterating the cargo en route with sea water to increase the volume and hence the payment received for it. The scheme was apparently this: A safe distance out from the Cuban port, a hose would be put overboard and sea water pumped into the tanks of molasses, increasing their content by as much as one-fourth to one-fifth, which in such a large cargo involved a considerable amount of money. With a heavy cargo and a slow-moving tanker, the rolling and tossing of the vessel would give ample opportunity for the sea water and molasses to become thoroughly mixed by the time of arrival at the port of delivery.

A number of difficulties conspired against detection. Small crews of low-paid and unscrupulous men were glad to take part in increasing

the cargo and sharing in the profits accruing therefrom. Placing detectives on the boats was of no avail, because the work might be carried on quietly in one part of the vessel while they were in another, or while they slept, or what was more likely, would be entirely omitted when there was the slightest suspicion of spying on the part of any member of the crew. To measure or weigh the amount of molasses at the time of loading and check it again at the time of delivery was entirely too costly and troublesome.

The natural thing under these circumstances was to turn to chemical analysis as a means of detecting the adulteration, on the probable assumption that addition of sea water to the molasses would add some element not otherwise present, or in such proportions as were not normally found, in the molasses. To this end several years were spent in devising methods and making exhaustive analyses of sea water, molasses, and of samples of the combination, even to determination of such rarer elements as might more probably be expected to be present in the one and not in the other, such as iodine, bromine, boron, manganese, and others, but all such analyses proved futile. Every element that was to be found in sea water was also found present in molasses, and further the composition of the latter is so highly variable that the addition of sea water did not change appreciably the proportion in which the elements occurred. Thus, after a considerable expenditure of time and energy, all of these methods proved useless.

Nor could the thickness or viscosity of the greatly diluted molasses be relied upon as a criterion, for as everyone knows from the classical saying "As thick as molasses in January", this material is the proverbial standard of fluid mobility, and its viscosity is exceedingly variable depending upon the natural amount of water it contains and also upon the temperature.

Chemical analysis and determination of the viscosity of the diluted molasses having failed, the hope of finding some readily recognizable and specific thing in sea water which was not in molasses finally suggested to one of the men conducting the investigation the thought of some organism, which happy idea soon resolved itself to consideration of the diatom. Here, theoretically, should be the ideal solution. First, here was an organism never normally present in molasses but always present in countless numbers in every quart of sea water, so that it must inevitably be added to the molasses upon dilution of the latter. Second, here was an organism unknown to most people, or, even if a captain should happen to be so well informed as to have full knowledge of these organisms, there would be no possible way to add the sea water and exclude the diatoms. They are so small that they would pass through any pump; and if an attempt were made to strain them out, they would soon clog the sieve and prevent

passage of the water. Third, once added, these diatoms have shells of such a nature as to be insoluble in the water or in any constituent of the molasses; they are the only organisms in the water that would persist indefinitely, resisting decomposition in the new medium, remaining as definite evidence of their origin. Fourth, the small, light shells of the diatoms could settle but very slowly through the thick molasses, and owing to the agitation by the vessel, would become evenly distributed throughout the mass and remain suspended in every portion of it. And last, but not of least importance, here was an object, abundant, and so specific in character as to serve as conclusive evidence and infallible proof of guilt merely upon sight, the presence of which could be ascertained in a moment simply by placing a drop of the sample under the microscope, obviating the necessity of long and troublesome chemical analyses or of other uncertain criteria.

With this prospect in mind, samples of sediment from several shipments of molasses were sent without delay to our laboratory, where abundant specimens of diatoms were found in them—diatoms which, furthermore, frequent the waters along the course traversed by these vessels. Upon the basis of this information, I am told, a number of captains had their sailing licenses revoked, and the method of detection was so simple and so sure that the practice of adulterating molasses by sea water dilution immediately became a mere episode of history. Here again is a unique application, based solely upon the characteristic structure of the diatom.

Thus the delicate shell structure, which is so variously and so admirably suited to the specific needs of the diatoms, is equally well suited to the environment and the conditions of nature under which they live, and at the same time offers qualities well adapted to many and diverse purposes and needs of man. Many more examples might be given of the numerous and unique uses of this material in all phases of industry, but the foregoing will suffice to illustrate that it is almost solely upon one unique quality—the microscopic form or structure—that the importance of the diatoms depends. Around the characteristic shape of almost infinitesimally small, thin-walled, glass shells great industries have grown. The power of little forces commands our deep respect. Thus is brought out the significance of the little quotation "Maximis in Minimis", used by Girard about 1860 in an obscure diatom paper, his only publication on the subject and one of no real scientific consequence. Girard was not a diatomist, and he wrote nothing about the subject worth remembering, but we may well pause to pay him tribute for the prophetic spirit which enabled him to see, beyond mere visual pleasure and professional interest, the deeper beauty and significance of the dainty objects he was observing: "Very great in very small things."

PLATE 1
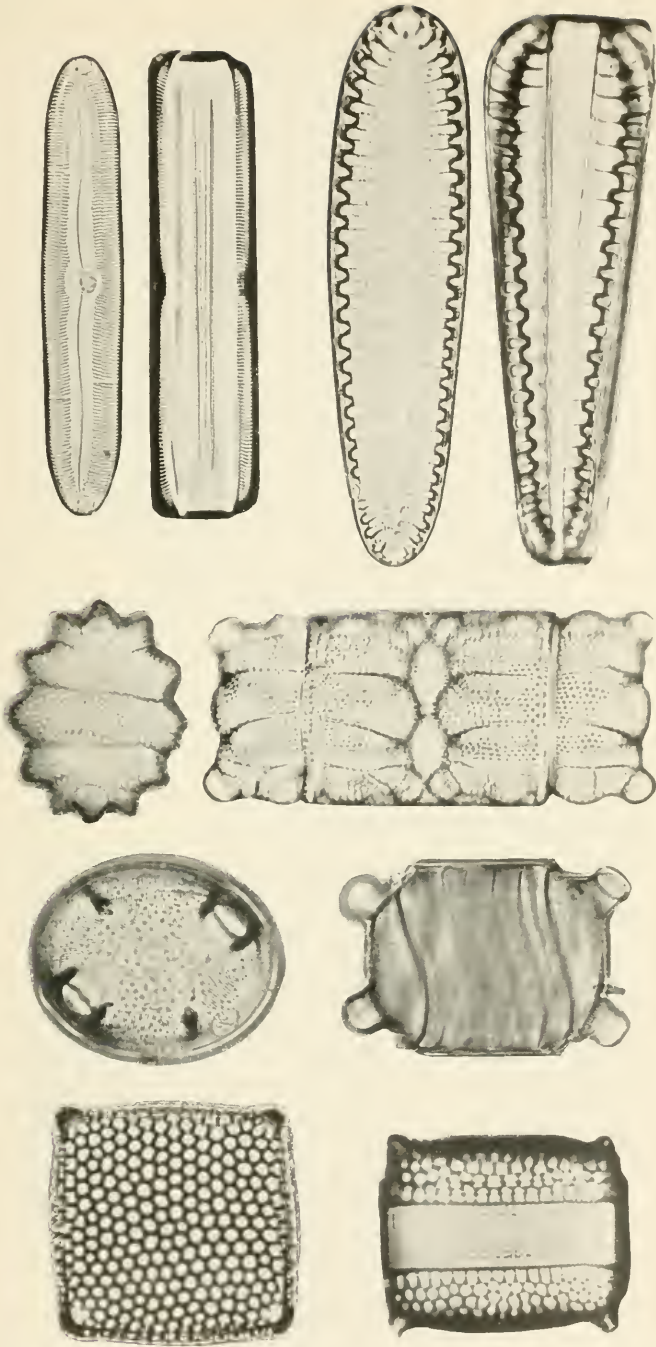
Face (*left*) and side (*right*) views of five typical diatoms showing the boxlike structure of these little plants. Magnified about 300 times.
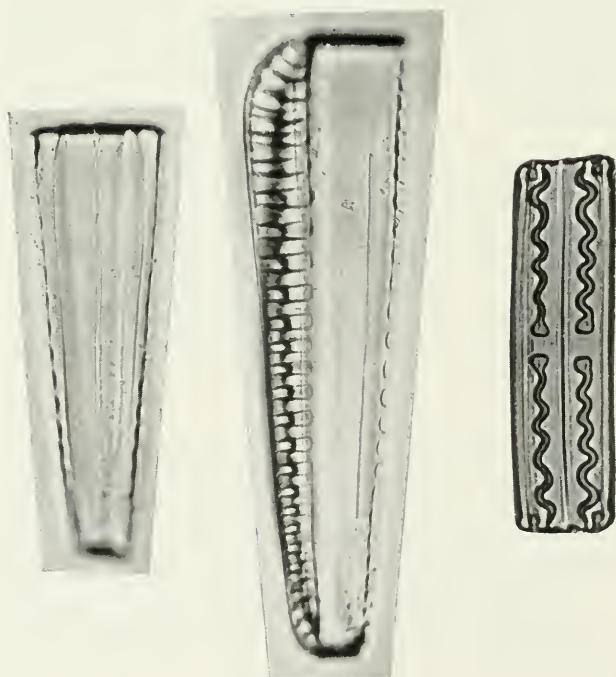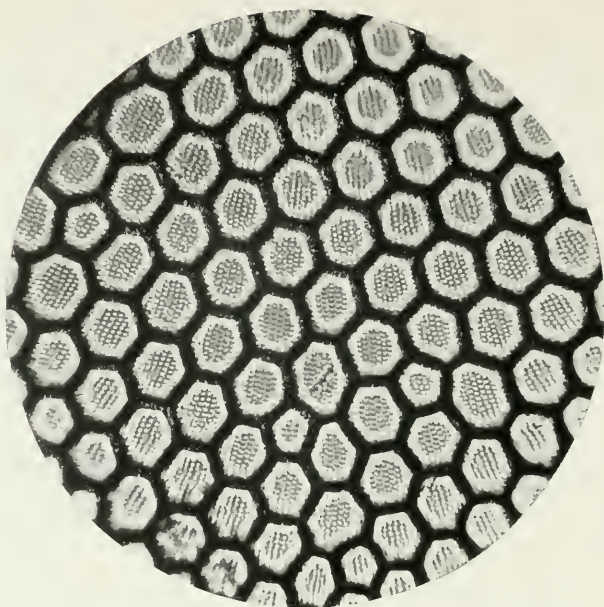
Upper, Highly magnified portion of shell of *Biddulphia favus* (Ehr.) V. H., showing secondary pore structure. × 800.

Lower left and center, A *Surirella*, showing dovetailed margin of girdle for attachment to the shell. × 300.

Lower right, *Grammatophora serpentina* Ehr., showing internal septal walls.

PLATE 3
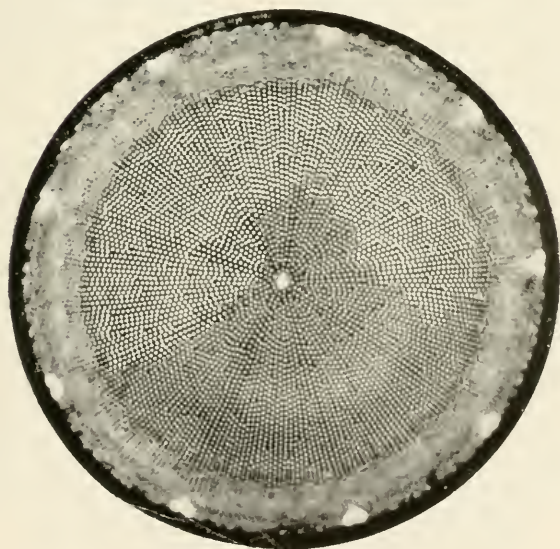
Upper, A piece of the shell of *Aulacodiscus margaritaceus* Ralfs (lower) with portion cut away, showing porous nature and double wall structure.
Center, Sections (edge view) through shell of *Aulacodiscus margaritaceus* Ralfs, showing double structure, connecting walls and pores.
Lower, Valve view of *Aulacodiscus margaritaceus* Ralfs. × 150.

PLATE 4
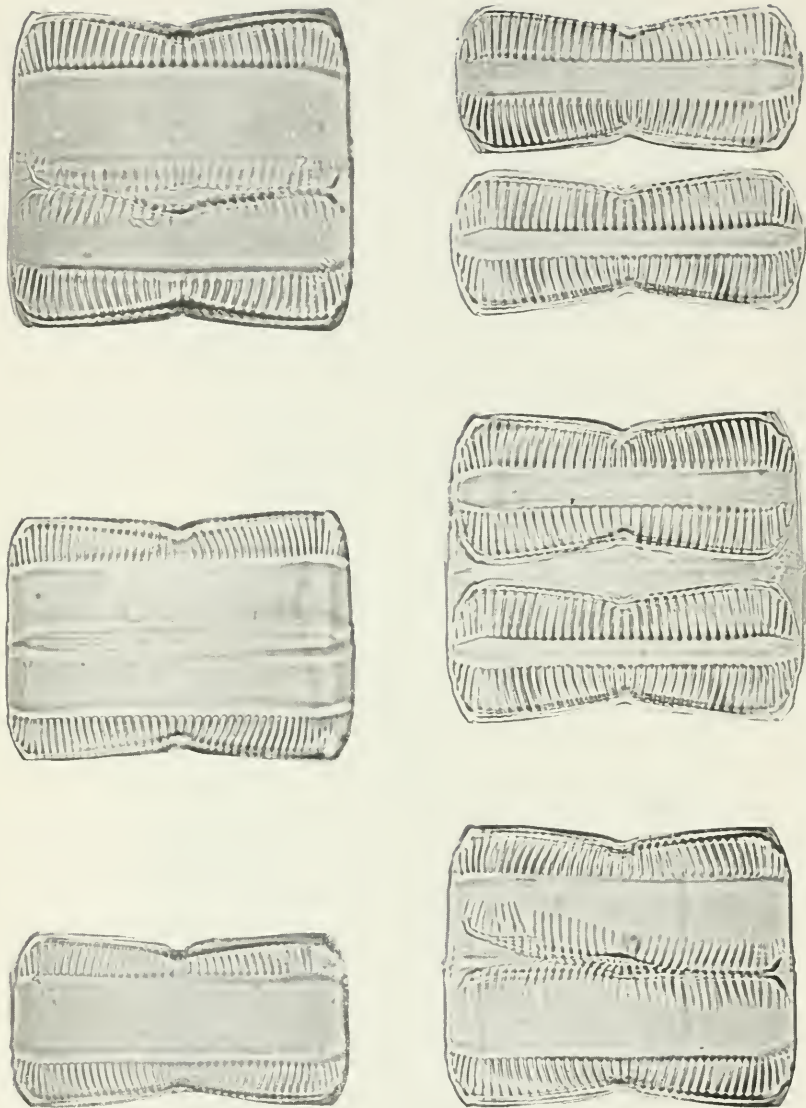
Relationship of structure to reproduction in a diatom, *Navicula cancellata* Donk. var. × 600.

Upper left, Young cell.
Upper center, Mature cell with widened girdle.
Upper right, Dividing cell starting to form new shells within.

Lower left, Formation of new shells further advanced.
Lower center, Formation of shells complete, and daughter cells ready to separate.
Lower right, Daughter cells after separation as new individuals.

PLATE 5
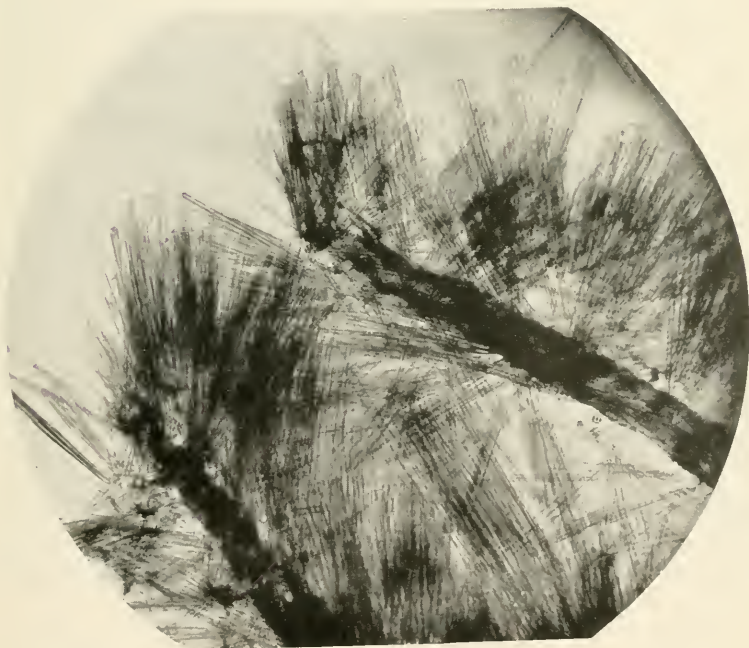
Adaptation of diatom structure to environment. $\times$ 100.

Upper, Plankton diatoms, with light spiny shells suitable for floating.
Lower, Mass of attached diatoms with spindle- or needle-shaped cells

PLATE 6
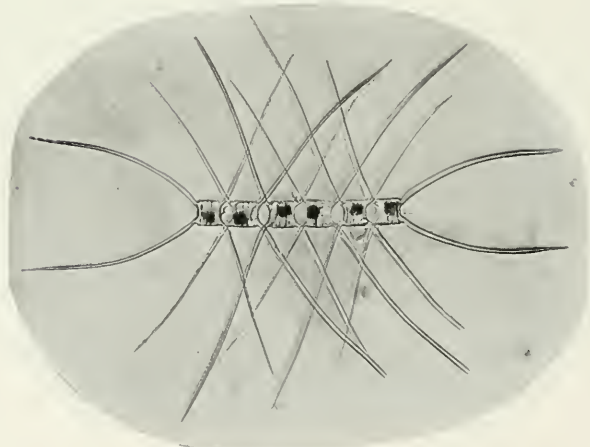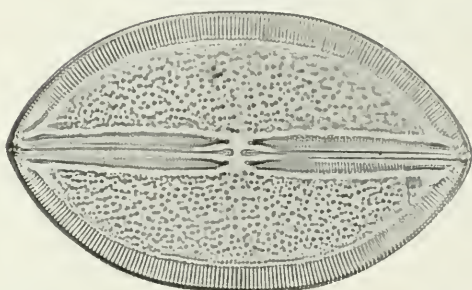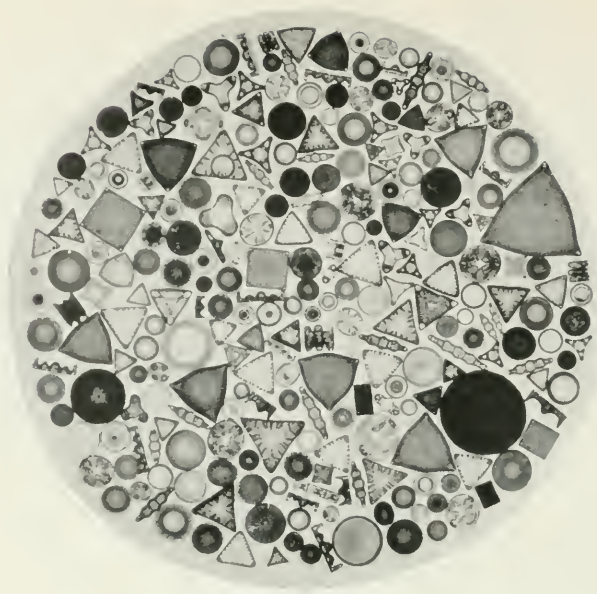
Upper, Group of fossil bottom diatoms from New Zealand. × 50.
Center, Navicula californica Grev. var. *campechiana* Grun. × 460.
Lower, Chaetoceros atlanticus Cleve, a floating form. × 80.

PLATE 7

Massive occurrence of diatomaceous earth, or diatomite, deposits.

Upper, Distant view of a mountain of diatomaceous earth at Lompoc, Calif. Though this picture gives every appearance of a landscape covered with snow, the picture was taken in the heat of summer, and the whiteness is due to the pure white nature of the earth.
Lower, Closeup view of au open cut in the above deposit.

PLATE 8
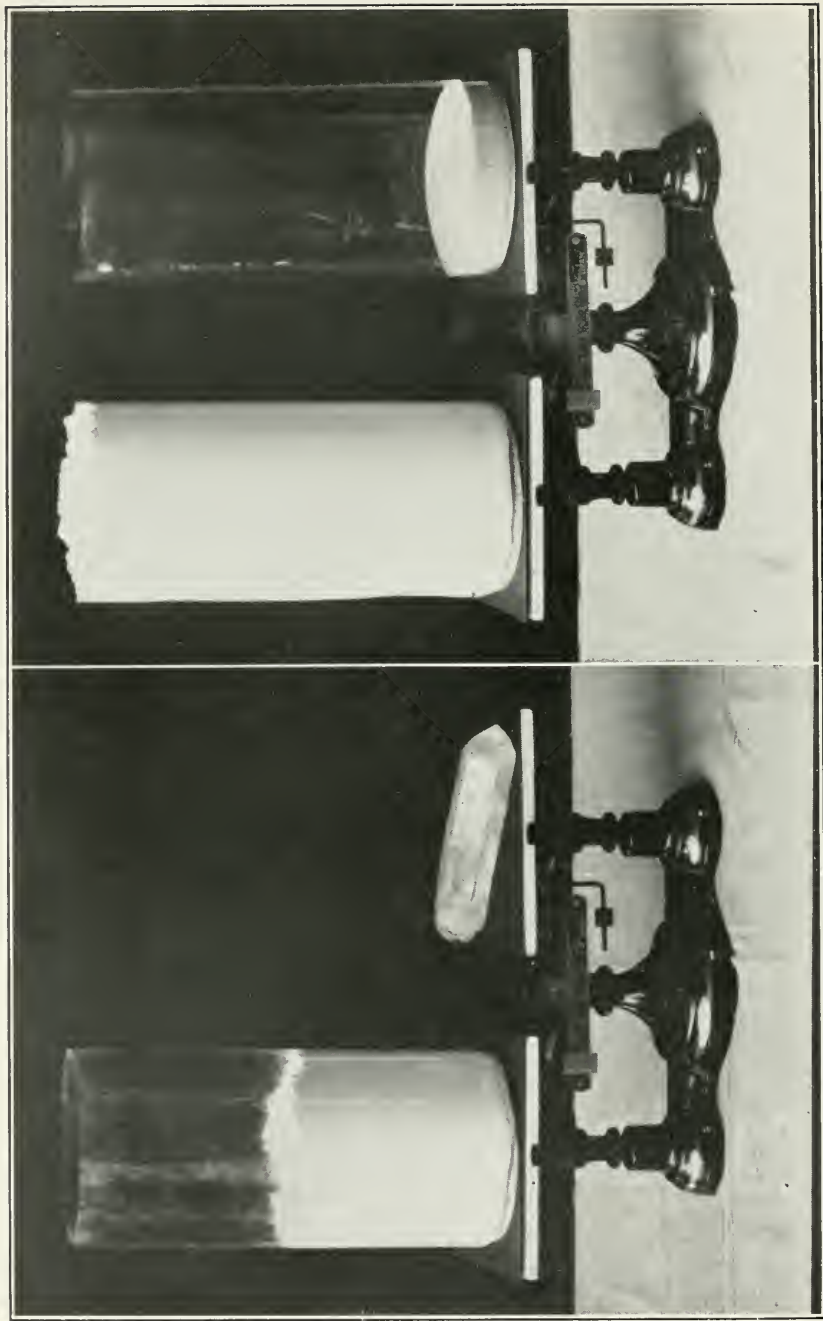
Comparison of relative weight and volume of diatomaceous earth with a quartz crystal (*left*), and with quartz sand (*right*). Chemically the materials—diatomaceous earth, quartz, and sand, are all the same—namely silica. The vast difference in apparent volume is due to the porosity of the earth because of the shape and structure of the diatoms.

PLATE 9
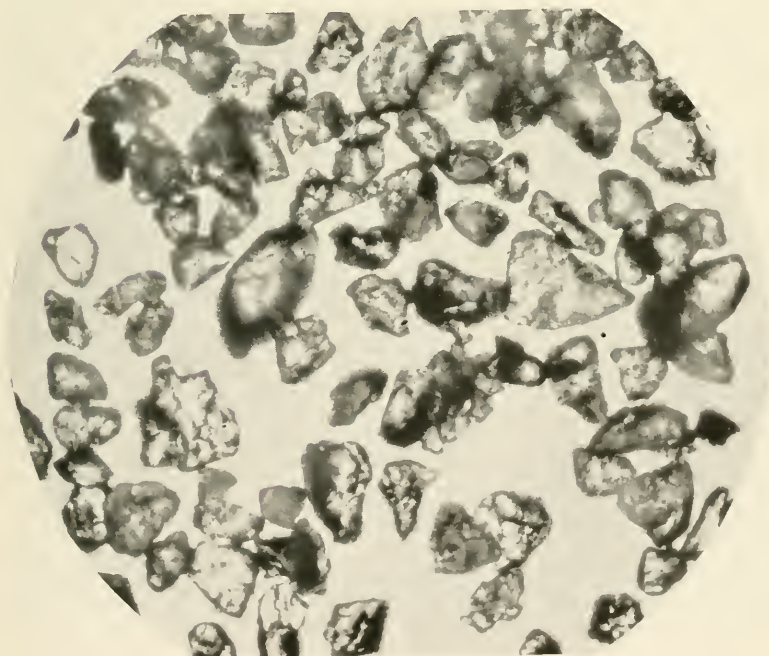
Comparison of particles of diatomaceous earth (*above*) and sand (*below*) at the same magnification. They are the same substance, but the sand is in solid lumps of silica. × 100.

PLATE 10

Florida diatomaceous earth (*center*) containing numerous small filelike diatoms as pictured above and below, *Eunotia zygodon* Ehr. and var., very useful for polishing silver.   Center, × 100; upper and lower, × 600.

PLATE 11
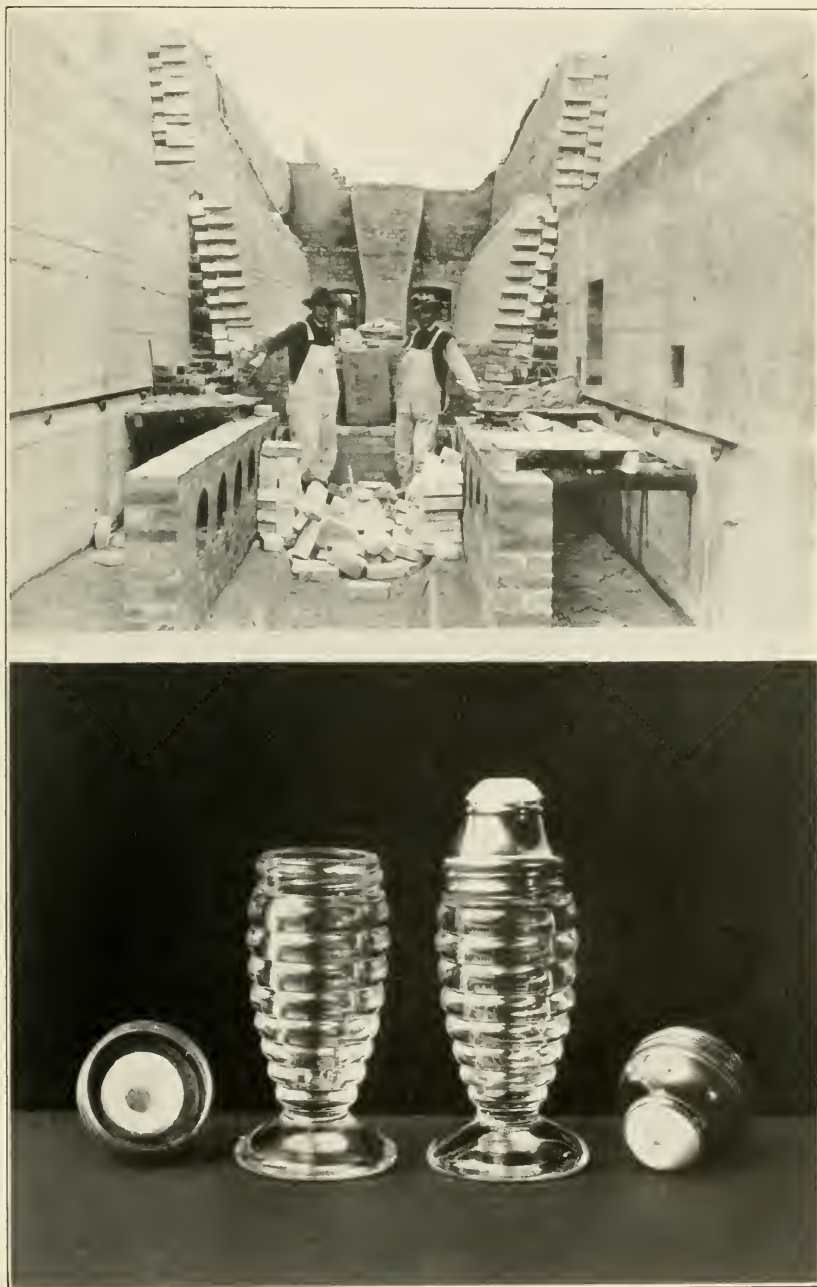
Upper, Laying light porous diatomaceous earth brick for heat insulation.
Lower, Salt cellar with weatherproof top made of diatomaceous earth.
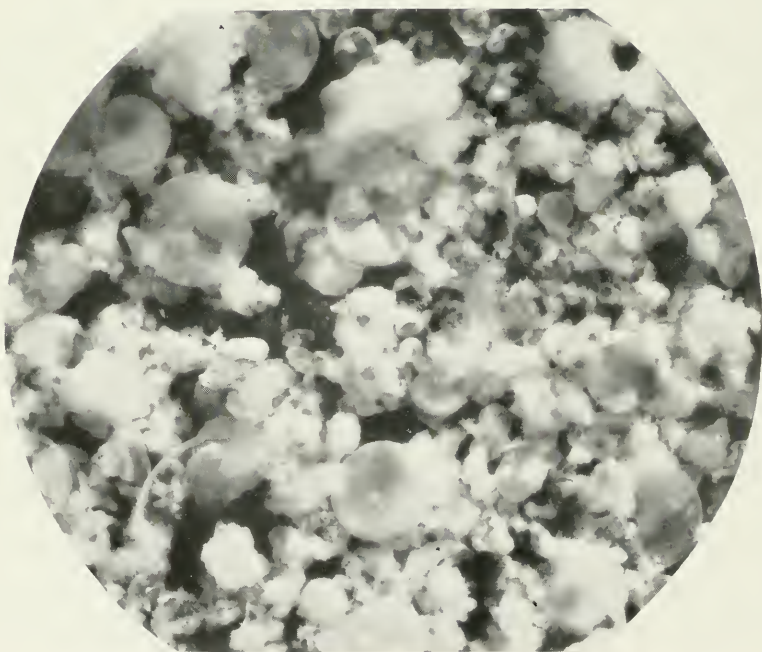
Upper, Photomicrograph of surface of smooth plastered wall. This surface echoes sound readily.
Lower, Photomicrograph of wall surface covered with diatomaceous earth. This surface catches sound
and stops echoes.
Magnification, × 100. Both surfaces would look smooth and white to the naked eye.

PLATE 13
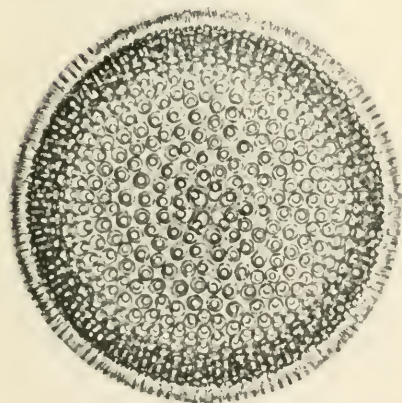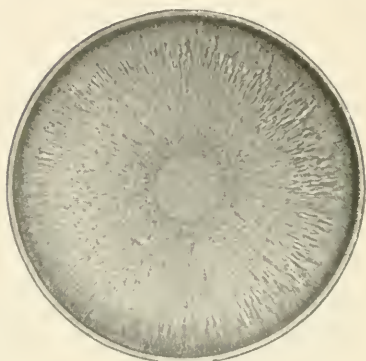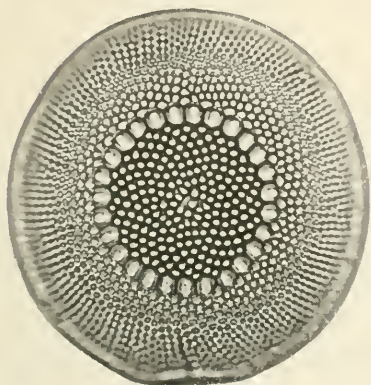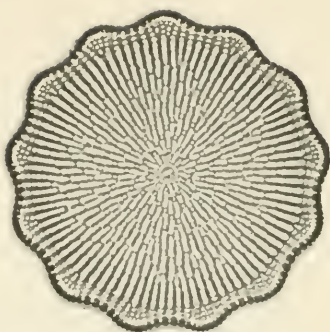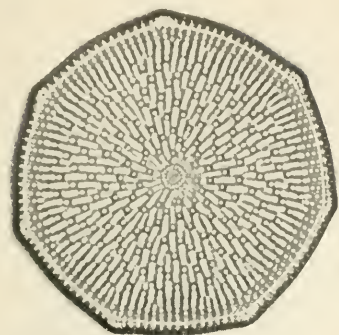
Various shapes of diatoms, and types of structure.

Upper left, Stictodiscus radfordianus Cast. × 320.
Upper right, Stictodiscus eulensteinii (Grev.) Cast. × 320.
Center left, Brightwellia pulchra Grun. × 500.

Center right, Hyalodiscus crepitans Mann. × 170.
Lower left, Coscinodiscus marginatus Ehr. × 300.
Lower right, Asterolampra vulgaris Grev. × 540.

PLATE 14
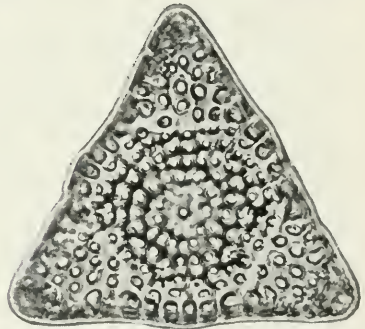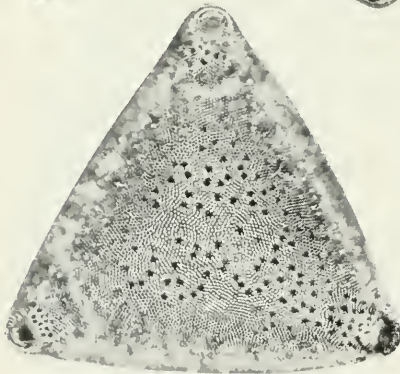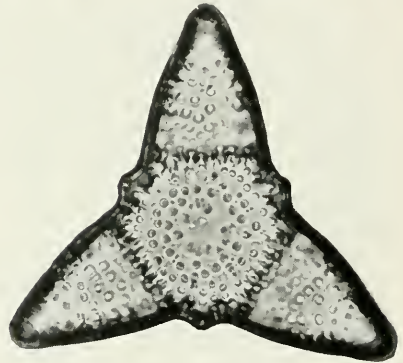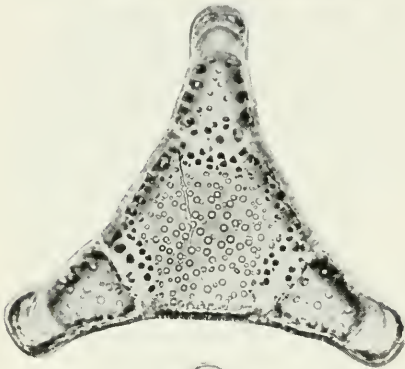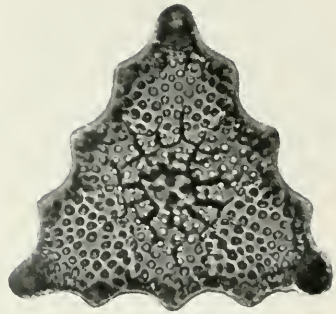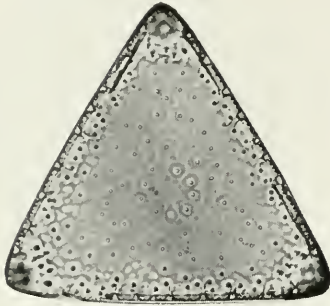
Types of diatom shape and structure continued.

Upper left, *Biddulphia major* Grove. × 300.
Upper right, *Biddulphia crenulata* (Gr. and St.)
    Mann. × 500.
Center left, *Biddulphia glandifera* (Grun.) Mann.
    × 400.

Center right, *Biddulphia archangelskiana* (Witt)
    Mann. × 480.
Lower left, *Biddulphia horrida* (Pant.) Mann. × 430.
Lower right, *Biddulphia cellulosum* (Grev.) Mann
    var. *Simbirskiana* O. M. × 480.
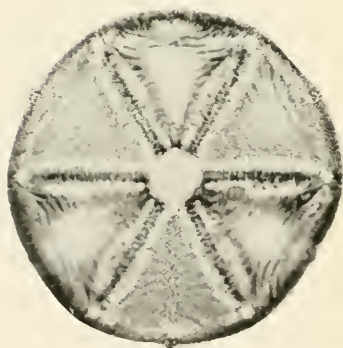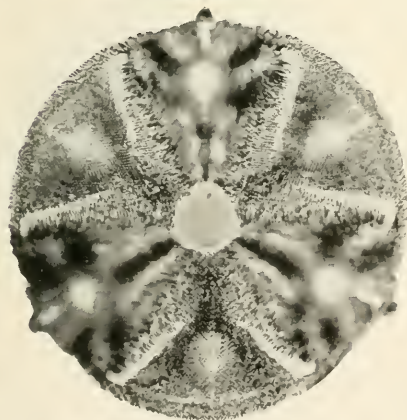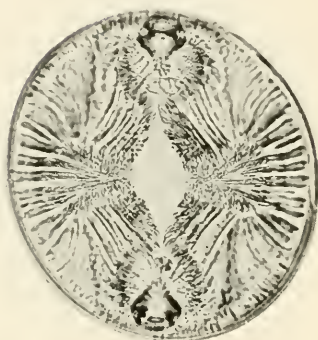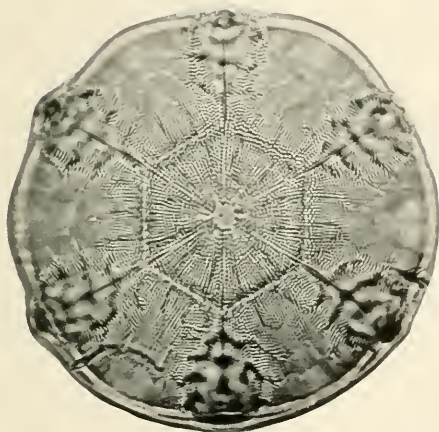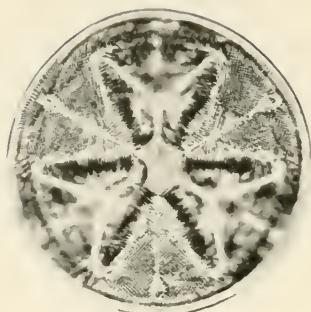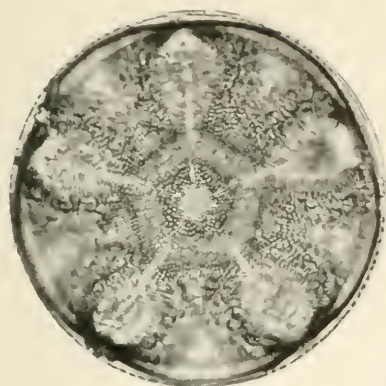
PLATE 16

Upper left, Stictodiscus truanii Witt. × 400.
Upper right, Coscinodiscus biradiatus Grev. × 500.
Center left. Actinoptychus splendens (Ehr.?) Shad.
× 300.
Center right, Coscinodiscus radiatus Ehr. × 450.

Lower left, Actinoptychus nitidus (Grev.) Grun.
× 500.
Lower right, Hyalodiscus van heurckii (Perag.) Mann.
× 400.
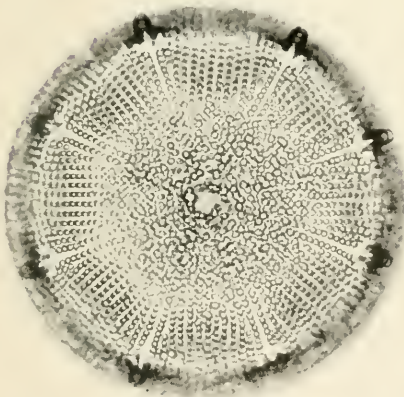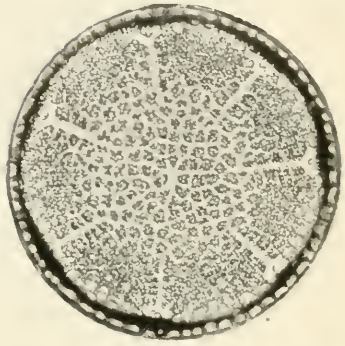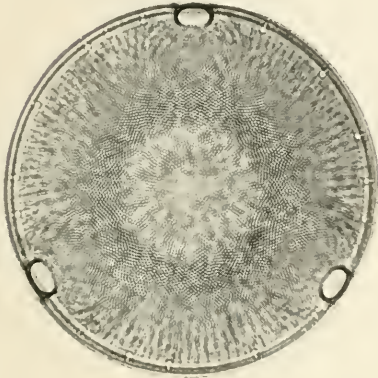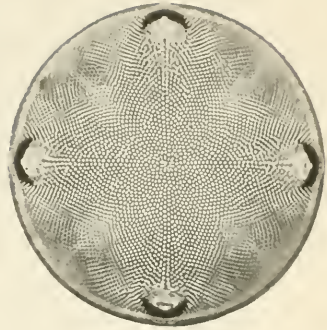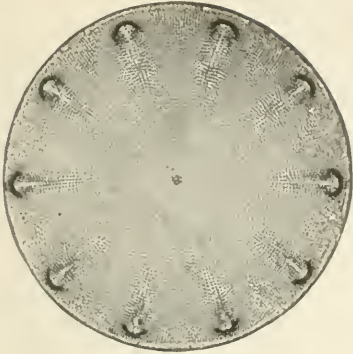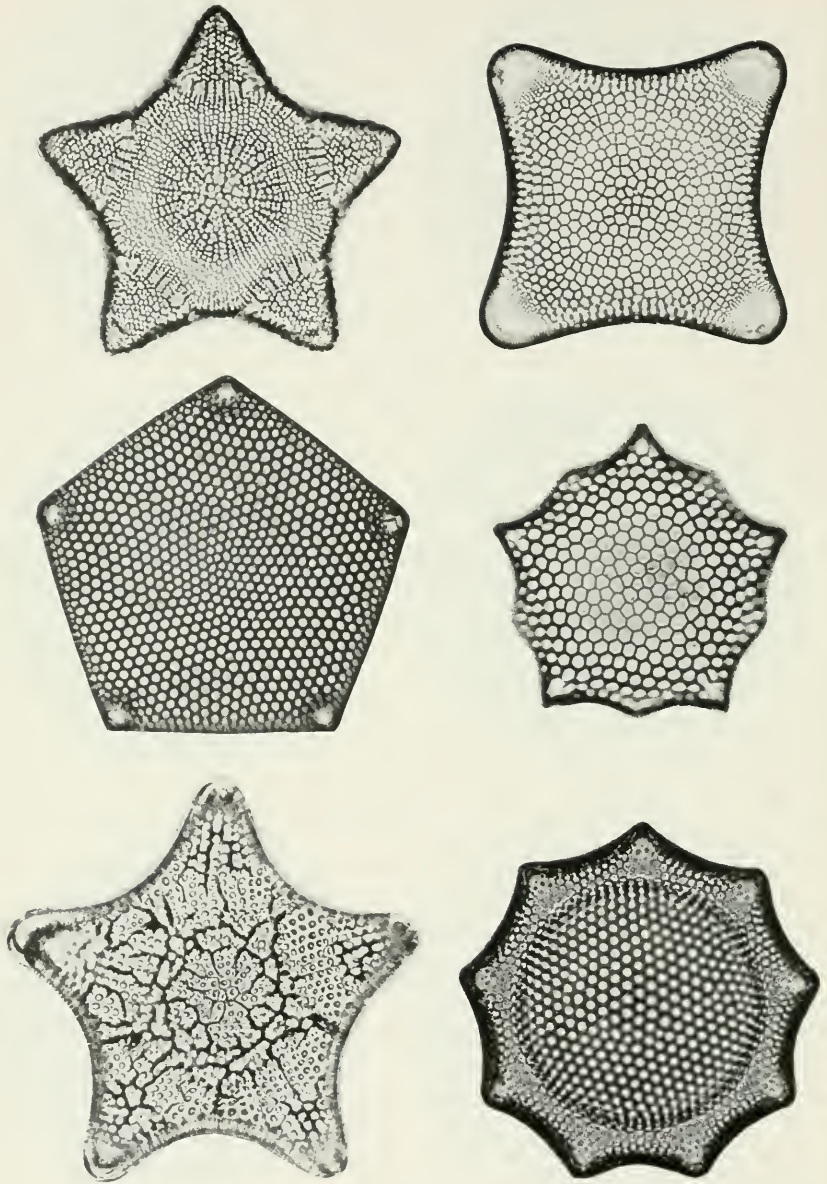
Upper left, *Biddulphia juncta* A. Sch. × 250.
Upper right, *Trigonium arcticum* (Bright.) Cl. × 540
Center left, *Biddulphia* sp. × 220.

Center right, *Biddulphia campechiana* (Grun.) Boyer.
      × 500.
Lower left, *Biddulphia pentacrinus* (Wall.) Boyer.
      × 450.
Lower right, *Biddulphia imperialis* Walker. × 150.

PLATE 19
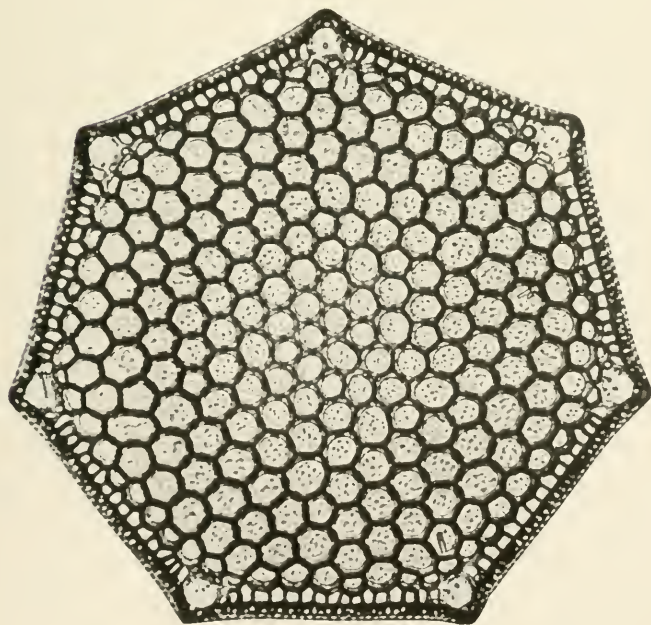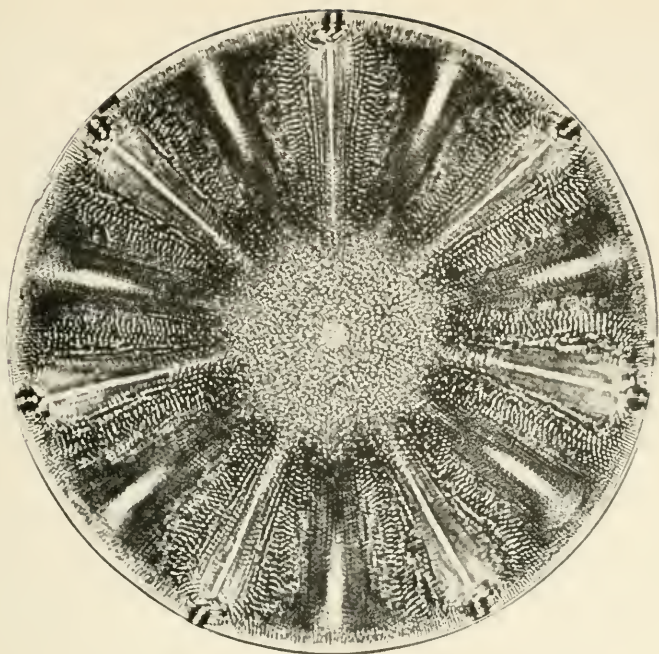
Upper, *Aulacodiscus janischii* Gr. and St. × 300.   Lower, *Biddulphia schmidtii* (Jan.) Mann. × 130.
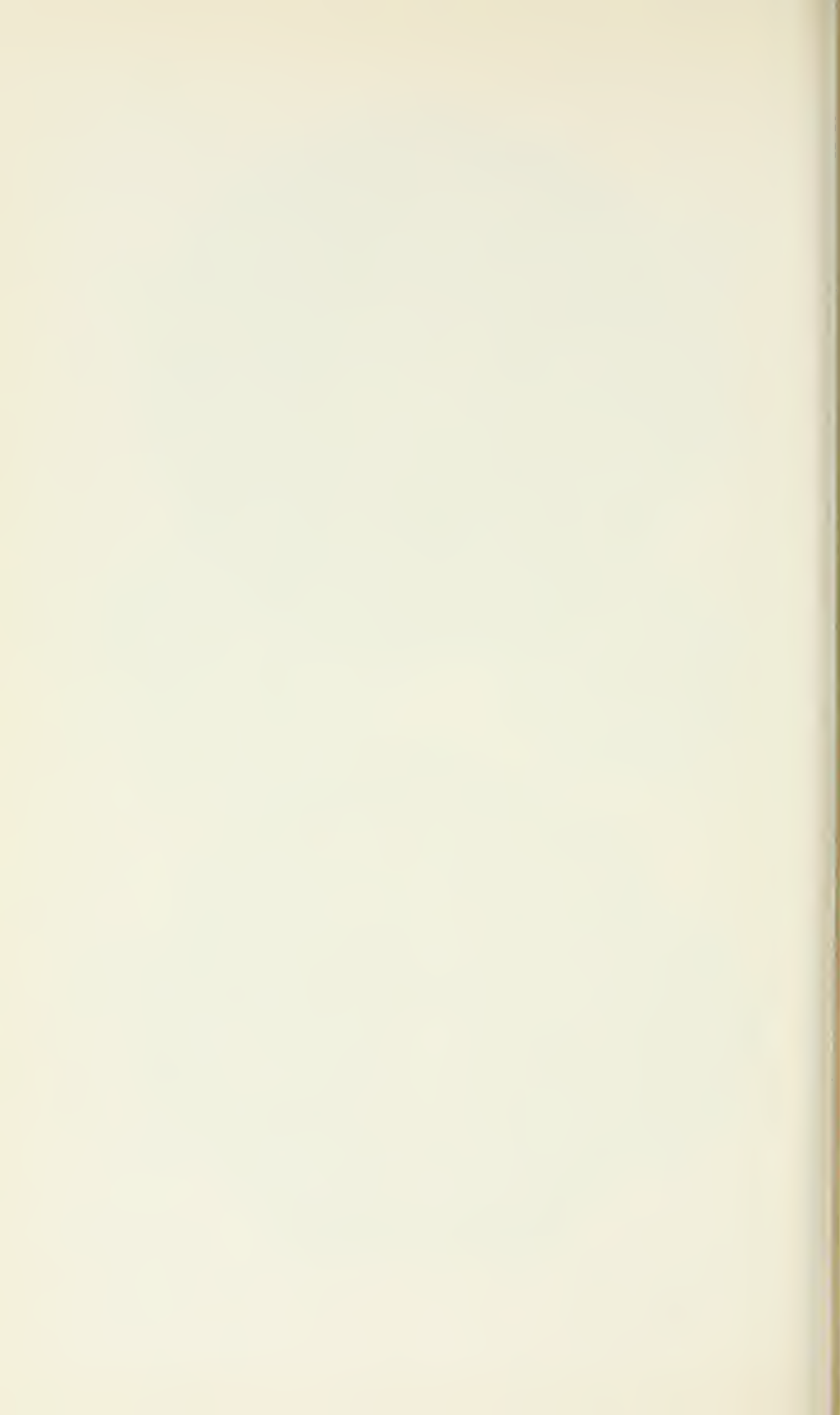
SOME ASPECTS OF THE PLANT VIRUS PROBLEM [1]

By Kenneth M. Smith, D. Sc., Ph. D.

Potato Virus Research Station, School of Agriculture, Cambridge

[With 2 plates]

There appears to be rather a tendency on the part of botanists to consider the study of plant viruses a dull subject and one without any sure foundation in fact. It is hoped, therefore, in this short article to show that, on the contrary, the subject is not only an intensely interesting one, involving problems of fundamental biological importance, but is also of extreme economic importance and that plant virus workers really have a definite problem in hand.

No one at the present time knows what a virus is, and this uncertainty as to its nature adds, perhaps, to the interest of the study. In speaking of a virus, stress is usually laid upon certain properties which are mainly negative in character such as inability to see the virus with the microscope, impossibility of cultivating the virus on media outside the host, and the fact that viruses cannot be held back by the usual bacteria-proof filters. Improving methods of technique, however, are showing that some of these qualities are merely relative and it is already possible to photograph some viruses by means of the ultraviolet light microscope and to devise filters which will allow viruses to pass or hold them back at will according to the pore size of the filter.

In speculating upon the nature of viruses, whether of animals or plants, as a whole, it is well to remember that they are a heterogeneous collection of disease agents, and it is by no means certain that they are necessarily all of the same nature. At one end of the scale is the virus of Psittacosis or parrot fever, the particle-size of which is 250 millimicrons (1 millimicron equals one-millionth of a millimeter) and which is in consequence within the range of the ordinary microscope. This virus appears to have a definite life cycle and is presumably a living organism. At the other end of the scale is the virus of foot-and-mouth disease which has a particle-size of about 10 millimicrons and is only two or three times the size of an oxyhaemoglobin molecule. It is difficult to conceive of this as a living organism. Certain plant viruses are also very small; the par-

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[1] Address to section K, British Association meeting, Norwich. Reprinted by permission from Science Progress, No. 119, January 1936.

ticle-size of tobacco necrosis virus is only 20–30 millimicrons, and that of a newly described tomato virus is only 17–25 millimicrons. Again, there is the recent claim of Dr. Stanley [14][2] of the Rockefeller Institute in Princeton that he has succeeded in producing a crystalline protein which has the properties of the virus of tobacco mosaic. This he considers to be an autocatalytic protein, i. e., one which acts upon the cells of the host in such a way as to compel them to produce more of the same substance.

For the present it will perhaps suffice to adopt the definition of viruses given by Gardner [5]— "as agents below or on the borderline of microscopical visibility which cause disturbance of the function of living cells and are regenerated in the process."

In this short survey of the plant virus problem, it will be possible to deal only with one or two of the more interesting aspects of the subject, and it is proposed, first of all, to discuss a few of the symptoms produced in affected plants. Since the pathological effect on the plant is almost the only criterion of the existence of a plant virus, the study of symptoms necessarily plays rather a large part. There are various kinds of virus diseases which may be loosely grouped together as follows, the mosaic type, where attack on the chlorophyll induces the formation of mottlings or rings (see pl. 1, fig. 1); the destructive type, which induces necroses of the cells in leaves and stems, and a third type which produces deformities or overgrowth in the affected plants.

Some of the mosaic viruses produce color changes in the flowers of affected plants. Perhaps the best known example of this phenomenon is the so-called "tulip breaking", in which tulips affected with a mosaic virus produce variegated flowers (pl. 1, fig. 2). Certain of these tulips with variegated flowers at one time fetched large sums of money owing to the mistaken idea that they were new varieties, whereas they were in reality only diseased specimens of self-colored varieties. References to this tulip "breaking" may be found in the literature of very early times. Thus, the first record is a description published in 1576, and other accounts of this variegation in tulips appeared in 1622 and 1670. It was in this latter account that the suggestion was first made that the variegated tulip might be diseased. In the Rembrandt exhibition recently held in Amsterdam were paintings of tulips by Dutch artists of the sixteenth and seventeenth centuries, and many of these tulips showed a typical mosaic infection. Just recently, growers of the favorite blood-red variety of wallflower have been perturbed by the appearance of an ugly yellow stripe or flecking in the red flowers and this has led to many complaints from customers that their color schemes have been spoiled;

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[2] Numbers in brackets refer to list of references at end of article.

similarly with self-colored stocks [10]. The variegation in these flowers has been shown to be due to a virus carried to the plants by a species of greenfly from virus-infected broccoli or cauliflowers in the neighborhood.

In the writer's opinion viruses play a larger part in the production of variegations in flower colors than is usually supposed. For instance, inoculations from the petals of common variegated mauve and white and mauve and yellow violas, picked at random from the garden (pl. 2, fig. 3), to healthy tobacco plants of the White Burley variety, produced in those plants a virulent mosaic disease. The virus is also capable of infecting several other species of Solanaceous plants. Experiment shows that the virus causing this variegation is a strain of cucumber mosaic virus (cucumber virus I).

Some of the mosaic viruses affecting ornamental plants may produce little effect on the plant other than the change in the color of the flowers. It is quite likely therefore that a systematic inquiry into the question would show that other familiar flower variegations may be due in part to virus infection. There seems, however, to be a common element in the appearance of this type of variegation, i e., a penciling or flecking of the colors and a break in the hard line dividing two colors.

The next question is the important one of how plant viruses are transmitted in nature from diseased to healthy plants. The majority of plant viruses depend upon insects for their dissemination from plant to plant, and this relationship between insect and virus is one of considerable interest. The insects concerned in the spread of plant viruses are nearly all of one type, a type of insect which feeds in a particular way which seems to be well adapted for the injection of the virus into the plant. These insects belong to the order Hemiptera and are of the sap-sucking type. The method of feeding of this type of insect is well demonstrated by means of the photomicrograph shown in plate 2, figure 2.

Insects are not merely mechanical vectors of the virus, but in all probability some kind of obligate relationship exists between the two. The following facts seem to bear this out: Certain viruses cannot be transmitted from diseased to healthy plants except by the agency of insects and often only by one species of insect or one type of insect and not by other closely related species; some insect vectors having fed once upon a virus-diseased plant remain infective for the rest of their lives without the necessity for further recourse to a source of virus infection. This suggests that the virus actually multiplies in the body of the insect. Further, some insects do not become infective until a minimum time has elapsed after feeding upon a virus-infected plant. This is often referred to, perhaps on insufficient grounds, as the "incubation period" of the virus in the insect. A

better term would be "a delay in the development of infective power within the insect." This delay may be as long as 10 days in some cases.

It is not possible to deal at length with the question of the insect relationships of plant viruses, but space permits touching upon some recent interesting work on this subject. Storey [15], working upon the leafhopper which transmits the streak disease of maize in East Africa, has found that there exist two distinct races of this insect, one race which can transmit the virus and one race which is unable to do so; these races are termed active and inactive, respectively. There is no visible difference between the inactive and active races, and both are of the same species. Further, Storey has shown that if a puncture is made with a fine needle in the wall of the gut or alimentary canal of the inactive insect, the insect then becomes capable of transmitting the virus. It would appear from this that there may exist some factor or factors connected with the structure of the wall of the alimentary canal in inactive insects which prevents the virus from passing through into the blood and so reaching the salivary glands whence it is injected into the plant.

The next point concerns the mechanism of movement of the virus in the plant. Since most viruses rapidly become systemic in their hosts, there is evidently an efficient means of transport about the plant. It has been shown by Bennett [1], Caldwell [2], and others that if the phloem in a portion of the stem of a plant is destroyed by steaming, the virus cannot pass over this bridge of dead tissue. In other words, the virus is moving in the phloem but not in the xylem. The disease will develop normally in whichever half of the plant is inoculated, but the virus will not pass from the upper to the lower nor from the lower to the upper half, across the bridge of dead tissue.

The general movement of a virus about the infected plant has been well demonstrated by Samuel [9]. His experiments show that there is no movement of tobacco mosaic virus from the inoculated leaf for a period of 3–4 days. The virus then passes out of the inoculated leaf and travels rapidly to the roots of the plant; about a day later it travels with equal rapidity to the top of the plant. In pot plants the more mature leaves become successively invaded from the top downward and from the bottom upward until the plant is completely invaded by the virus.

The movement of the virus in the plant thus seems to be of two kinds: first, a very slow cell-to-cell movement via the connecting protoplasmic bridges until the phloem stream is reached, when the main and most rapid movement about the plant begins. Further confirmation of this is afforded by some experiments with a newly discovered virus known as tobacco necrosis [13]. This virus produces only necrotic symptoms and thus etches out, as it were, its own move-

ment through the plant. Photographs have been taken at 2-day intervals of the path followed by the virus in the leaves of cowpea (*Vigna sinensis*). The first six photographs show merely a gradual increase in size of the lesion at the point where the virus has entered the leaf. As soon, however, as the virus enters the phloem it begins to travel rapidly through the leaf, moving in 48 hours over a much greater distance than in the whole of the preceding 12 days' slow cell-to-cell movement.

On another aspect of the subject two interesting discoveries have recently been made: firstly, it has been found that some plant viruses exist in a number of closely allied strains, and, secondly, it has been shown that infection with one strain of a virus will immunize a plant from infection with another strain of that virus. Space will not suffice to allow of a discussion as to whether these strains actually arise by mutation from existing strains, but the evidence rather indicates that this is the case.

The immunity conferred upon a plant by a virus strain against other strains of the same virus is of the nonsterile type. There is apparently no question of the production of antibodies, and it is the presence of the first virus which inhibits the entrance of the second strain. This type of immunity is well shown in the case of potato virus X [8], tobacco [6] and cucumber mosaic viruses [7] and by the virus of tomato streak [11]. All these viruses exist in strains and the "green" and "yellow" strains of the tobacco or cucumber viruses are particularly suitable for this kind of experiment. If a healthy tobacco plant and one systemically infected with a "green" strain of tobacco mosaic are inoculated with a "yellow" strain, the healthy plant develops the yellow spots characteristic of this virus, while the plant already infected with the "green" strain is protected against invasion by the "yellow" strain. A similar protective action is exerted in the case of a plant infected with a "yellow" strain against invasion by the "green" strain. It should perhaps be emphasized that the presence of one virus in a plant is no bar to the entrance of a second virus of a different type; the cross immunity holds good only for like viruses and virus strains. This kind of immunity therefore is likely to prove a useful tool in the work of classifying viruses and in distinguishing like from unlike viruses in those cases where diagnosis by symptoms alone is unreliable.

A possible practical application of this type of immunity lies in the protection of a crop from infection with a severe virus by previous artificial infection with a mild strain of the same virus. Here, however, lie a number of pitfalls, chief of which is the unfortunate liability of certain viruses, even when in a mild form, to give rise, jointly with another virus of a different type, to a

much more severe disease than is produced by either virus acting separately.

Mention must be made of a comparatively new method of approach to the plant virus problem, i. e., the discovery that the intraperitoneal injection of rabbits with plant virus extracts induces the production of antibodies in these animals. These antibodies react specifically with the antigen (virus sap) in some observable way. Three types of immunologic reactions have been demonstrated, complement-fixation, precipitation, and neutralization of the pathogenic properties of the virus. Such neutralization is specific for each virus; thus, tobacco mosaic virus is inactivated only by antitobacco mosaic serum, and tobacco ringspot virus only by antitobacco ringspot serum and so on. The cross specificity is absolute, and the addition to any of the viruses of a heterologous antiserum exhibits no effect. This specificity, however, does not extend to distinctions between virus strains even when the strains produce very different symptoms in the host plants (Chester [3]).

This new technique is likely, therefore, to prove another useful tool in the difficult task of classifying and differentiating plant viruses.

Since viruses are so often spoken of as filter-passing or ultra-microscopic, and described by other adjectives referring to their small size, it may be of interest to give a few details of the actual magnitude of some viruses. The sizes of virus particles can be measured with fair accuracy by means of ultrafiltration through collodion membranes, the pore size of which can be measured. These membranes are prepared by a special technique devised by Dr. Elford [4] of the National Institute of Medical Research at Hampstead, and the process of their manufacture is too complicated to describe here. It has been found by the application of this technique that plant viruses vary very much in their particle size, ranging from 75 to 100 millimicrons for a potato virus down to 17–25 millimicrons for a new tomato virus. The comparative chart shown in figure 1 will give some idea of the range of size of different plant and animal viruses.

In conclusion it is proposed to give a short account of an interesting new virus, because it well illustrates the kind of problem with which the virus worker is sometimes faced. It has been found at Cambridge [12] that a high proportion of the normal stock of healthy tobacco plants carry a virus in the roots but not in the stem and show no signs of disease during the whole of their life. Under certain conditions, however, in the winter and early spring the virus may pass up into the plant and develop disease symptoms in the lower leaves. Unlike most other plant viruses, this virus does not become systemic in the host. Further, and this is the most in-

teresting point, tobacco seedlings which by available methods of inoculation have been shown to be virus-free, yet contain the virus in their roots in quite large quantities some 5 weeks later. The following experiment illustrates this. Seed from a White Burley tobacco plant grown in the insect-proof glasshouse was sown in sterilized sand in a "Cellophane" cage in the glasshouse. From the resulting seedlings a number of small plants were chosen and all the roots

Bacillus prodigiosus	750 mμ (diameter)	
Psittacosis	275 mμ	
Vaccinia	150 mμ	
Rabies	125 mμ	
Rous sarcoma	100 mμ	
Fowl plague	75 mμ	
Potato virus x	75 mμ	
Bacteriophages	25-60 mμ	
Tobacco mosaic	30 mμ	
Haemocyanin	24 mμ	
Yellow fever	22 mμ	
Foot and mouth disease	10 mμ	
Oxyhaemoglobin	5·6 mμ	
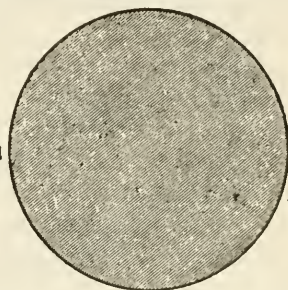
FIGURE 1.—Table showing particle sizes of representative animal and plant viruses with those of some bacteria and protein molecules for comparison. (1 mμ = 1,000,000th millimeter.)

cut off except that one root was left on each plant. The roots of each plant thus removed were ground up and the resulting paste inoculated separately to three or four cowpeas, a plant which is extremely sensitive to the virus. The tobacco plants were then repotted in sterilized soil and allowed to grow on; from this number 48 plants,

the roots of which had given no reaction upon the cowpeas, were selected for a second test. This was made, again to cowpeas, 5 weeks after the first test. The plants were by this time about 8 inches across with a well-developed root system, and showed no unusual symptoms. Of these 48 plants 32 gave a virus reaction. In considering these results certain other facts must be borne in mind; exhaustive tests make the explanation of outside infection by seed transmission unlikely, though the possibilities of air- and water-transmission, via the soil, cannot be excluded. The virus is not insect borne.

There seem to be three possible explanations of this problem: first it may be assumed that the virus is present all the time in the stem, but present either in a nonvirulent form which requires to gain virulence by concentration in particular cells of the root, or else in a dilution too great to give a positive reaction on inoculation. This theory, of course, involves seed transmission of the virus in undetectable form or quantity. The second possible explanation is that the virus is arising spontaneously within the plant. The third explanation, and perhaps the most likely, is the existence of a mode of virus transmission at present quite unsuspected.

Virus workers have long dallied with the idea that a virus might arise *de novo* within the host. Such a suggestion is attractive in some ways and it would explain many things which are at the moment obscure. If viruses are considered as organisms or at least possessing some of the attributes of life, the suggestion of their heterogenesis is repugnant. If, on the other hand, Stanley's view that a virus may be an autocatalytic protein is accepted, then there seems no particular reason why the theory of spontaneous development of the virus within the host should not also be accepted. It is, however, at present still an open question, and much work remains to be done before this question can be answered.

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PLATE 1
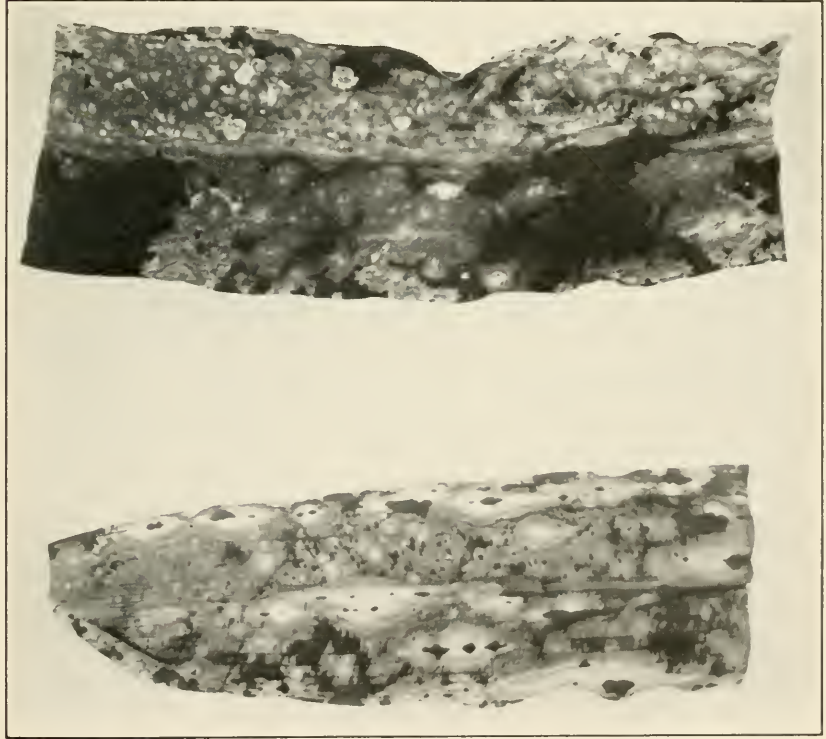
F. C. Bawden.

1. MOTTLING AND RING PATTERNS PRODUCED BY CERTAIN VIRUSES OF THE MOSAIC TYPE.

J. P. Doncaster.

2. TULIPS WITH VARIEGATED OR "BROKEN" FLOWERS DUE TO INFECTION WITH A VIRUS.

PLATE 2

J. P. Doncaster.

VIOLAS SHOWING A COLOR VARIEGATION CONSIDERED TO BE CAUSED BY A VIRUS.
Note the penciling and flecking of the petals.

Ann. Appl. Biol.

SECTION OF A POTATO LEAF WITH THE BEAK OF A SUCKING INSECT IN SITU.
Insects which feed in this manner are most concerned with virus transmission.

SUN RAYS AND PLANT LIFE [1]

By Earl S. Johnston

Division of Radiation and Organisms, Smithsonian Institution

[With 4 plates]

The sun is the earth's reservoir of energy. All terrestrial activity is related directly or indirectly to the sun. In the third Arthur lecture Dr. Abbot discussed how the sun's radiant energy warms the earth,[2] and showed the dependence of the weather on variations in the energy of the sun itself. Here we shall consider the influence of radiant energy on plant life.

In green plants a process takes place in the presence of light that has determined and continues to determine the destiny of nations and the very existence of man. This process is technically known as photosynthesis. By this process carbon dioxide and water are united in the presence of chlorophyll, the green plant pigment, to form the simple sugars. These products are elaborated into starch and other carbohydrates and into proteins, organic acids, fats, and other plant synthates. Many of these compounds are food, not only for the green plants themselves, but also for animals and nongreen plants. These foods, on being assimilated, are built into new structures formed in growth and the stored energy is released.

Green plants, by this process of photosynthesis, supply the living world with food. The struggle for land rich in food resources has more than once influenced the destiny of ancient as well as modern people. Through the centuries the availability of food has determined to a large extent the size of centers of population. Transportation, to be sure, enters as an important factor, but this has been governed in general by fuel. Coal beds and oil fields are resources of potential solar energy resulting directly or indirectly from photosynthesis. Here again man, in his struggle for existence, battles by brute force or cunning for supremacy. Thus one is tempted to continue ad infinitum with examples showing the relationship of solar

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[1] The fifth Arthur lecture, under the auspices of the Smithsonian Institution, Feb. 25, 1936.

[2] Abbot, C. G., How the sun warms the earth. Smithsonian Ann. Rep. 1933, pp. 149–179, 6 pls., 20 figs., 1935.

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energy acting through the green plant to the activities on earth and to the destiny of man.

Solar energy received at the surface of the earth is far from being a constant value. It differs greatly from time to time with respect to its duration, intensity, and quality.

The length of day or duration of sunlight varies with the latitude and the season. At the Equator there are approximately 12 hours of darkness and 12 hours of light for each day throughout the entire year. The other extreme is reached at the poles, with 24 hours of light during the summer season and 24 hours of darkness during the winter season. Intermediate latitudes have sunshine values between these extremes.

The intensity of sunlight varies inversely as the square of the distance from the sun. Since the earth's orbit is elliptical with the sun at one focus, a difference of approximately 7 percent may be effected with the earth at perihelion in January and at aphelion in July. Other variations in intensity are due to dust particles and water vapor in the atmosphere. An increase of 1 mm pressure in water vapor decreases the radiation intensity about 2 percent. Intensity also varies with the angular displacement of the sun from the zenith, which is governed by the season and the time of day. Changes in actual amount of energy radiated from the sun also influence the intensity of solar energy reaching the earth's surface.

The quality or, more accurately expressed, the wave length of sunlight also varies. The white light of the sun with the maximum energy in the yellow becomes richer in red as the sun drops from the zenith to the horizon. This variation in wave-length distribution is due to the lens effect of the earth's blanket of atmosphere and to the differential absorption of light as it passes through it. Sunlight is relatively richer in blue and violet during the summer in the North Temperate Zone than it is in winter. This is likewise true for high altitudes.

No wonder a wide range in type of vegetation is encountered over the face of the earth. To be sure, temperature and moisture are important factors in bringing about this variation, but after all variations in temperature and moisture are caused by variations in the solar energy reaching the earth.

A wealth of information can be obtained by observing the character of plant growth in natural habitats. The accumulation and organization of knowledge concerning the correlation between plants and their environments fall in the realm of plant ecology. A study of the activities of individual plants with emphasis on individual plant processes as these are affected by single environmental conditions is restricted to plant physiology. The ecologist endeavors to

obtain relative values; the physiologist aims to determine the absolute values of such relationships.

As a result of observations and studies by plant ecologists and physiologists, many interesting relationships have been found between light and the structure and growth of plants. The brilliant colors of alpine flowers have been attributed to the presence of ultra-violet light in the clear sky of high altitudes. The broad succulent leaf growth within a dense tropical forest can be attributed in part to a reduced light condition. Many interesting structural modifications in desert plants are brought about by a change in moisture and light. Although such observations are interesting, but little quantitative data can be obtained until plants are grown under controlled conditions.

The plants around us are registering within themselves the total effects of the climate, sunlight being one of the important factors of the climatic complex. Perhaps the most familiar record of the plant's environment is that recorded by trees. The type of rings, their thickness and shape, give to those familiar with the language a story of the climate during the life of the tree. The researches of Dr. Douglass (1932) on tree rings have given us a most instructive picture of the climatic conditions prevailing during the past centuries.

Use has actually been made of the plant as an integrating instrument for measuring climatic conditions. While a student at the Johns Hopkins University, I conducted an experiment in which the climatic conditions of a greenhouse for a period of 13 consecutive months were recorded by a set of "standard" buckwheat plants (Johnston, 1921). The plants were grown for 4-week exposure periods. A new period began every 2 weeks. Measurements of stem height, dry weight, leaf area, and transpiration were made at regular intervals. Simultaneous measurements of evaporation, radiation, and temperature were also obtained. Two series of tests were conducted, one under ordinary conditions of an unshaded greenhouse, the other within a cheesecloth enclosure in the same greenhouse. Some of these data are summarized in the form of graphs and shown in figure 1.

The rates of stem elongation, dry weight increase, and leaf-area increase had high summer values and low winter ones. These values increased during the spring and decreased during the autumn. The rates of transpirational water loss varied throughout the year in a similar manner. For the rates of stem elongation, and possibly also for that of transpiration, it appears that a period of low values occurs about the summer solstice.

The greenhouse climate during this particular year, as measured by these plant processes, appears to have been most favorable to

the general growth of these plants during two separate periods; one in early summer, the other in late summer. Even with the usual application of artificial heat, the winter efficiency for plant growth remained very low.
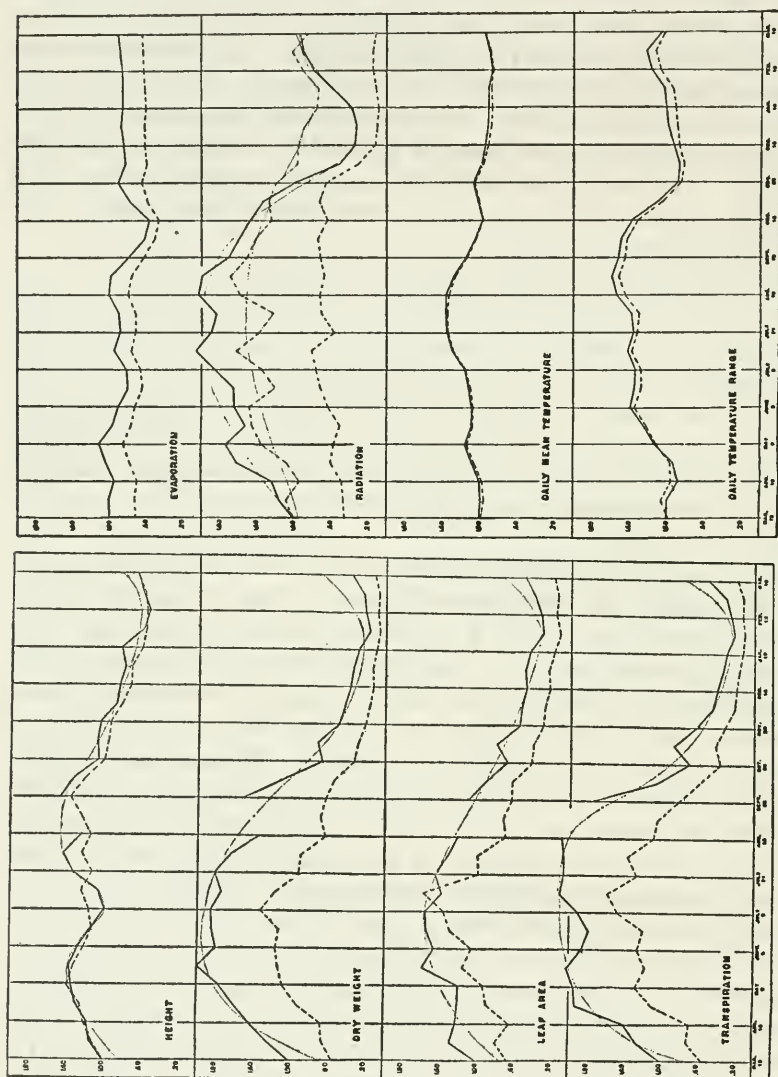
FIGURE 1.—Graphs of plant and instrumental data all plotted from the four-week relative values. Data from the exposed series are indicated by continuous lines, those from the sheltered series by dash lines, and those of sunshine duration by the dash-dot lines. The dotted lines are smoothed graphs.

The evaporation measurements as determined with the white atmometers (Livingston, 1915) showed somewhat higher and more uniform values for the winter than for the summer. The most pronounced seasonal fluctuation was shown by the indices of total radiation. These measurements were obtained by determining the difference in water evaporated from the black and white atmometers.

There is fairly good agreement between these values and those of actual sunshine duration. The temperature values showed a rather decided seasonal variation, with high summer values and low winter ones.

The climatic efficiency values within the cheesecloth chamber appear, in general, to have been lower than those in the unshaded greenhouse, the exceptions being the values for stem height and for leaf area for the periods about June 21.

Although the interpretation of the plant values in terms of those derived from the instruments offers many difficulties, nevertheless several striking features of this environmental complex are registered in the records of both plants and instruments. The one to

ELECTROMAGNETIC RADIATION
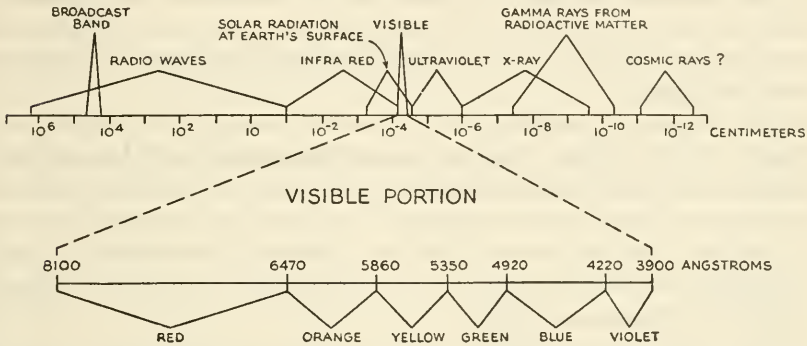
FIGURE 2.—Diagram showing position of infrared, visible, and ultraviolet radiation in the great electromagnetic spectrum. Data from Deming and Cottrell and from "Handbook of Chemistry and Physics."

which attention is especially directed is the general agreement to be observed between the radiation values and those of dry weight and leaf area.

These general relationships between sunlight and plant growth are interesting enough to warrant a more detailed examination by reviewing briefly the effects of the various components of sunlight upon the different physiological processes that take place in plants. The sunlight which we shall consider is actually a very small fraction of the great electromagnetic spectrum.

As will be seen in figure 2, this immense series of wave lengths extends from far beyond the short gamma waves produced from radioactive matter such as radium to the long wireless waves. The magnified portion shown below includes the wave lengths of the visible spectrum from red to violet. This, together with a section in the infrared and another in the ultraviolet, comprises the wavelength regions for our present discussion.

In addition to the action of the different wave lengths of light, the factors of intensity and duration exert definite effects on the growing plant. Without going too much into detail we shall first consider some of the interesting growth responses induced by different lengths of daylight.

DURATION EFFECTS

Everyone has observed the remarkable regularity with which our common plants come into flowering with the advent of the different seasons. Among the early blooming plants in spring are the arbutus and forsythia, then the dogwood, and later the iris, and so on into the summer and fall when the asters and chrysanthemums hold the center of the stage. Although temperature plays an important role, yet the main contributing climatic factor controlling flower production is the length of daylight. Plants like the cosmos which normally flower in autumn when the days are short can be made to flower at other seasons of the year by artificially limiting them to definite hours of light.

Numerous experiments have been carried out by Drs. Garner and Allard (1920), of the United States Department of Agriculture, which conclusively demonstrate that plants may be made to produce flowers or to continue their vegetative growth by merely regulating the number of hours of exposure to daylight. The lengths of the daily light and dark periods were controlled by moving the plants in and out of darkened sheds.

These authors conclude from their many studies that plants which are sensitive to length of day fall naturally into two groups which are divided by a fairly definite critical light period. "In the short-day group flowering is initiated by day lengths shorter than the critical, and in the long-day group flowering is initiated by day lengths in excess of this critical period. * * * The essential characteristic of the less sensitive or indeterminate group of plants is that they possess no clearly defined critical light period."

An interesting economic application made of the influence of the length of daylight on plants is that relating to Maryland Mammoth tobacco. This unusually large plant was discovered in southern Maryland, but under the long periods of summer daylight it would not flower or set seed. By growing the plant in the greenhouse during the winter, seed could be produced. Likewise seed could be secured easily by growing the plant in southern Florida during the winter. On the other hand, this short-day plant could be kept growing vegetatively in the winter by supplementing the daylight with electric light. Two such winter-group plants are shown in plate 1, figure 1. The one on the left was exposed to the short-day length,

the other to a long-day length. Flowers were formed in the one case but not in the other.

Attention should be called to two other interesting plant responses to the length of the light period. These are illustrated by two experiments also taken from the work reported by Garner and Allard (1925). In one of these the upper and the lower sections of a yellow cosmos plant were exposed to 10 hours of light. The middle section received light during the entire long summer days. Both the top and bottom sections of the plant responded to the characteristic short-day light exposures and soon bloomed, while the middle section remained vegetative to the long-day exposure. This would indicate a localized response.

In another set of experiments (Garner and Allard, 1931) artificial light was used, and the plants were exposed to this illumination for a total of 12 hours per day. One group received 12 hours of continuous light and 12 hours of darkness. The other groups were alternately illuminated and darkened for periods of the following durations: 1 hour, 30 minutes, 15 minutes, 5 minutes, 1 minute, 15 seconds, and 5 seconds. Again using the yellow cosmos as an example, the interesting growth response is shown in plate 1, figure 2.

A progressive decrease in height, size, and weight of the plants, and an increase in etiolation was noticed down to the 1-minute interval. Further shortening resulted in marked improvement in growth and general appearance. All exposure intervals less than 1 hour were equally unfavorable for flowering. In one of the long-day plants tried (rocket larkspur) none of the shorter alternations showed a retarding action in flowering, although the general growth responses were similar to those of the short-day plant. These are exceedingly interesting growth responses to the duration of light and to date no satisfactory explanation has been given.

A most interesting method of forcing greenhouse crops has been found by Dr. R. B. Withrow (1933, 1934, 1936), of Purdue University. Lamps of very low wattage used as supplementary lighting sources for a number of greenhouse-grown plants produced responses which were seemingly out of all proportion to the treatment applied. The plants were illuminated for several hours each night in addition to the natural light they received during the day. The intensities varied from less than 1 foot-candle to over 100 foot-candles. In plate 2, figure 1, very little difference in flowering is noted between the aster (Heart of France) receiving 100 foot-candles and the one receiving 0.3 foot-candle. Flowering even occurred with 0.1 foot-candle. This was an intensity about double that of moonlight on a bright winter night at Lafayette, Ind.

Dr. Withrow was next interested in determining what wave lengths of his Mazda lights were effective in bringing about the flowering.

He tried both long-day and short-day plants and found the responses different. For example, in a long-day plant like the stock, the greatest response occurred in the red for the wave-length region of 6500 to 7200 A, as illustrated in plate 2, figure 2. With short-day plants such as cosmos and salvia, supplementary red light hindered flowering. Likewise, a Mazda light of 1 foot-candle prevented these plants from flowering. This is clearly shown for salvia in plate 2, figure 3.

Dr. Withrow divides the plants he has so far studied into three general groups: Those showing (1) no response of commercial value, such as the rose and carnation, (2) earlier or increased flowering or both, as stock, aster, shasta daisy, pansy, and (3) delayed flowering, as the chrysanthemum.

These few illustrations show some of the interesting plant responses brought about by the proper lengthening or shortening of the light period. In addition to a general and scientific interest, these responses have a real commercial value.

The so-called "sleep movements" of plants such as shown by the clover, sorrel, mimosa (sensitive plant), and *Desmodium gyrans* are undoubtedly related to the normal daily light and dark periods. In the morning these plants open or unfold their leaves and at night close them. This daily rhythm of opening and closing becomes so fixed in the protoplasm of the plants that when they are placed in continuous darkness the movement may continue for several days; each day, however, it becomes weaker until it finally ceases.

INTENSITY EFFECTS

There is scarcely a place on the earth's surface either too light or too dark for plants to grow. On the deserts we find plants adapted to intense sunlight. In caverns receiving little or no sunlight other types of vegetation are found. One of these "dark-loving" plants is a tiny moss (*Schistostega osmundacea*) equipped with a plate of cells forming a set of lenses capable of focusing the scattered light on its chloroplasts, those small bodies bearing chlorophyll which is essential for photosynthesis.

Many plants exposed to daylight of varying intensities have developed certain characteristic responses which in many cases have proven beneficial. The English ivy (*Hedera helix*), for example, arranges its leaves in a mosaic pattern that exposes a maximum area to the light. Other plants, like the compass plant (*Silphium laciniatum*) and the wild lettuce (*Lactuca scariola*) turn the edges of their leaves in a general north-south direction. Thus when the light is weakest in morning and evening, the flat surfaces of the leaves are in a position to receive a maximum amount of light, whereas at noon, when the light is most intense, these surfaces are more or less par-

allel with the sun's rays and receive a minimum amount of direct radiation.

Even the interior of leaves frequently undergoes structural changes with increasing or decreasing light intensity. The microscope reveals in some instances a change in position of the chloroplasts within the leaf cells, as illustrated in figure 3. These chlorophyll-containing bodies arrange themselves across the path of weak beams of light as shown in the upper figure, *a*. In strong light these bodies migrate to the side walls, thus permitting a minimum amount of exposed surface, *b*.
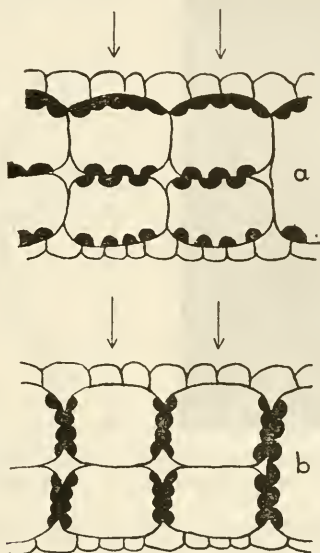
FIGURE 3.—Diagram showing position of plastids in cross-section of a leaf (*a*) in diffused light and (*b*) in intense light. Arrows indicate direction whence light is coming. After Stahl.

All increase of dry weight in plants depends on their assimilating carbon dioxide from the air under the influence of light. All the carbon in coal and wood, grains, oils, and many other indispensable products comes, in the final analysis, from this source and depends for its energy content on sunlight. In figure 4 the gas exchange between a green leaf and its immediate environment is represented. It will be noted that while respiration goes on continuously in light and darkness, photosynthesis takes place only in light.

Sunlight intensity varies under natural conditions from 0 at night to as much as 10,000 foot-candles on a bright summer day. Most plants grow very well in intensities considerably under the high figure just noted. In experiments with artificial light good growth has been obtained with intensities as low as 2,000 to 3,000 foot-candles. Numerous experiments carried out by William H. Hoover at the

Smithsonian Institution, as well as those performed elsewhere, clearly show that plants under normal atmospheric conditions grow better and better as the light intensity is increased up to a certain value. Beyond this value there is no further increase. The excess radiant energy is apparently wasted so far as the process of photosynthesis is concerned. One naturally wonders why it is impossible to "push" the plant in its manufacture of sugar and starch. What holds back this all-important work of the plant? The answer is simple enough when the factors of photosynthesis are examined. Some idea of what
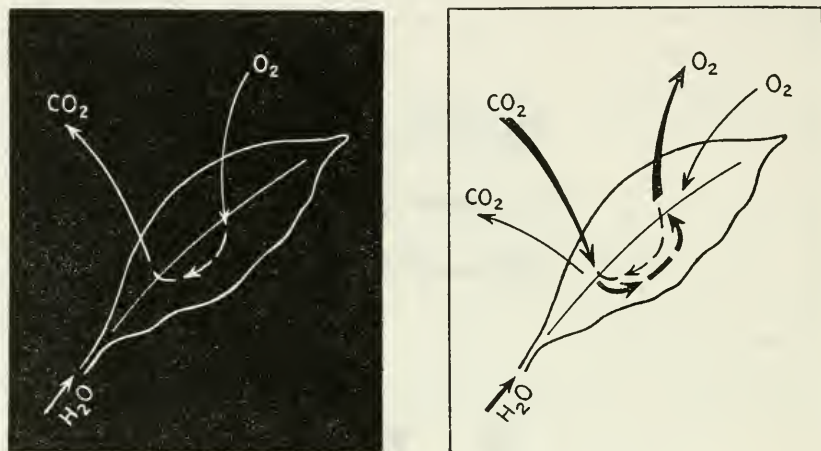
FIGURE 4.—Diagram representing the exchange of oxygen and carbon dioxide which takes place in darkness (left) and light (right).

takes place in the plant during photosynthesis may be expressed in the shorthand of chemistry:

$$6CO_2 + 6H_2O + light \rightarrow C_6H_{12}O_6 + 6O_2$$

(carbon dioxide)   (water)   (sugar)   (oxygen)
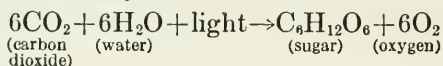
The raw products that are used up in this process are carbon dioxide and water. Normal air contains about 0.035 percent of carbon dioxide. Thus one can understand that as the process of manufacturing sugar is speeded up by increasing the light intensity there will come a point at which the rate is slowed down by a lack of carbon dioxide, which at this low concentration flows into the plant at a limited rate. If, however, the level of the reservoir of carbon dioxide be raised by increasing its concentration in the air surrounding the plant the work done by the plant should be increased as the light intensity is further increased. This is exactly what was done during the past two summers in experiments with wheat (Johnston, 1935 b).

Three plots of wheat plants were employed in the first experiment (pl. 3, fig. 1). The one in the foreground was open to normal

air, the two in the background were enclosed by glass cases 5 feet high. Two pieces of fly netting were stretched across the top of each to reduce wind action. A pipe carrying a mixture of air and carbon dioxide opened into the plot on the right. At the end of the experiment the growth in this carbon-dioxide-treated plot was compared to that in the enclosed control plot on the left and to that in the open control plot in the foreground.

The appearance of the three crops at harvest is shown in plate 3, figure 2. *A* received air enriched with carbon dioxide to about four times that of normal air. *B* was grown in the enclosed control plot, and *C* in the open. The experiments of the second summer were very similar. It was shown in these experiments that air enriched with carbon dioxide (1) increased the tillering of the wheat, (2) greatly increased the weight of straw, increased (3) the number and (4) weight of heads, (5) increased the number of grains produced, and (6) slightly delayed the time of heading.

The practical application of aerial fertilization with carbon dioxide and the source of supply of carbon dioxide in sufficient amounts for field work are still unsolved problems. Its application to greenhouse culture appears to be more promising.

WAVE-LENGTH EFFECTS

The chemical reaction to which attention has been drawn is, perhaps, the most important in the whole world, for life itself would perish without photosynthesis. It is therefore interesting to examine it from all points of view. On the chemical side, much remains to be done. The complexity of organic chemical reactions, the little-understood effectiveness of so-called catalysts, the behavior of enzymes, of colloids, of hormones, altogether make up a field of research of the utmost interest, but of extreme difficulty, for the student of plant growth.

Furthermore, photosynthesis takes place under the influence of light. Its energy is derived from radiation. The question immediately suggests itself, "What rays are utilized in this reaction?" Although many qualitative studies of this problem have been made, there is but little quantitative data on the subject, especially with economic plants. Mr. Hoover (1937), of the Smithsonian Institution, has made quantitative determinations of the dependence of an important higher plant—wheat, in this case—on the wave length of light for the assimilation of atmospheric carbon dioxide. He used the ingenious Christiansen filter (McAlister, 1935) to separate narrow bands of the spectrum from the beams of a group of Mazda lamps surrounding the tall glass tube within which the wheat was grown. Atmospheric temperature and moisture were controlled. A

continuously operating device measured the change of carbon-dioxide concentration in the slow air stream which bathed the plants. The effects observed depended on the color of light employed. Three series of experiments were made. In one, Mazda lamps with Christiansen filters were the light sources. In a second series, the discontinuous line spectrum of the mercury arc combined with glass filters gave monochromatic sources. In the third, sunlight itself, passing through a large-sized Christiansen filter some 60 feet from the plant,
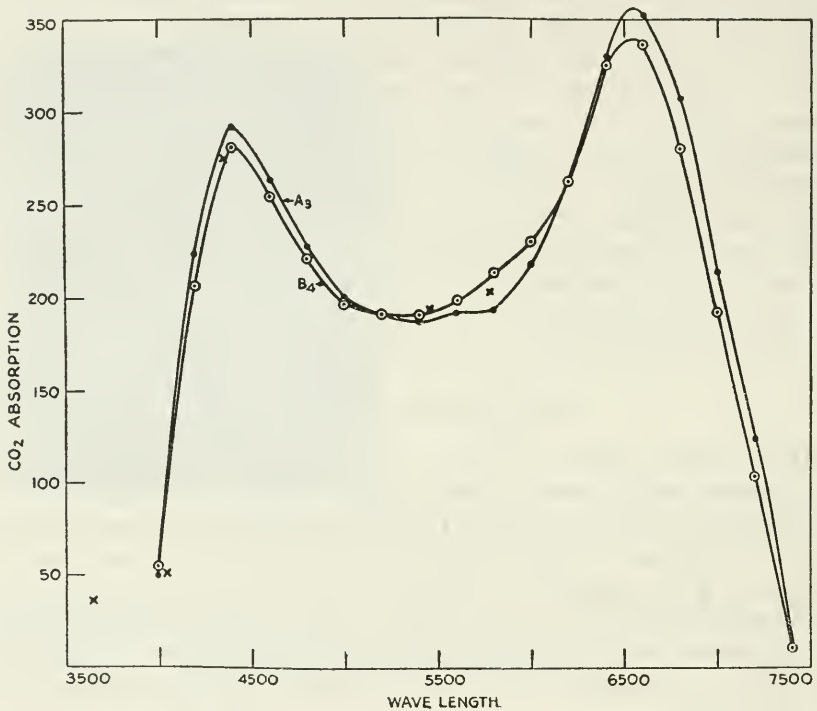
FIGURE 5.—Wave-length effect of light on carbon dioxide assimilation of wheat plants. A_3, the corrected form of the curve obtained with the large Christiansen filters; B_4, the corrected form of the curve obtained with the small Christiansen filters. Points marked X, the results obtained with the line filters and quartz mercury arc.

furnished floodlights of nearly monochromatic rays. The results, illustrated graphically in figure 5, were in close accord from all three series.

Thus it is seen that red rays are most promotive, blue rays second, green and yellow rays useful, and the infrared and the ultraviolet contribute nothing to the assimilation of carbon dioxide in wheat. Experiments with other plants are proposed.

The response of English ivy to light intensity has already been mentioned. In this response the leaves arrange themselves in a mosaic pattern with a maximum of leaf surface exposed to light.

The leaf stems or petioles turn toward the light source. Ordinary house plants such as the geranium show this same response as they grow by a well-lighted window. Unless such plants are turned occasionally, the stems will grow out toward the light, giving them a lopsided appearance.

From superficial observations it would appear that light hinders or retards elongation of plant cells. It is frequently noted that the stems of many plants grow more rapidly at night than during the day. Potatoes send forth greatly elongated shoots in a darkened cellar; if these same potatoes were permitted to remain in strong light, the sprouts would be very much shorter and the internodes greatly reduced.

In the case of plants illuminated on one side it is noted that the shaded sides of the stems have stretched more than those receiving direct illumination. The uneven rate of growth on the opposite sides results in curved stems and a general appearance of the plant turning toward the light. This characteristic bending is very well illustrated with the oat sprout shown in plate 4, figure 1. Because of its convenience in handling and its ready response to light the oat seedling or coleoptile, as it is technically called, has been used very extensively in phototropic studies.

Although superficial observations clearly indicate that the sensitivity of the plant toward radiant energy is such that it reacts differently to light and darkness, the question as to its sensitivity to different colors or wave lengths of light is not so readily answered. To obtain an answer a plant might be placed half-way between two equally intense lights, for example blue and green, and the direction of bending noted. The plant's sensitivity to different colors could thus be determined in a general way. Such experiments have been conducted by the Smithsonian Institution to determine growth sensitivity to wave lengths of light (Johnston, 1934, 1935 a).

The general procedure used in studying the wave-length effects in phototropism, as this type of response is termed, is to place an oat seedling between two lights of different color. After a time interval the seedling is examined for a one-sided growth. If, for example, the seedling being exposed to blue light on one side and to green on the other, a distinct bending was noted toward the blue light, it was then known that the blue light exerted a greater retarding action, since the side of the seedling toward the green light grew more, thus bending the seedling toward the blue light. The lights were then so adjusted as to increase the green, or decrease the blue intensity. Another seedling was used and the process repeated until a balance point was obtained where the effect of one light neutralized the effect of the other in such a manner that the seedling grew vertically.

When this point was determined a specially constructed thermo-couple replaced the seedling, and by means of a galvanometer the two light intensities were measured.

From a number of such experiments the curve shown in figure 6 was constructed. This curve illustrates the sensitivity of the oat seedling (plotted vertically) to the wave lengths of light (plotted horizontally). The sensitivity increases rapidly from 4100 A to 4400 A, then falls off somewhat to about 4575 A, and again rises to a secondary maximum at about 4750 A. From this point the sensi-
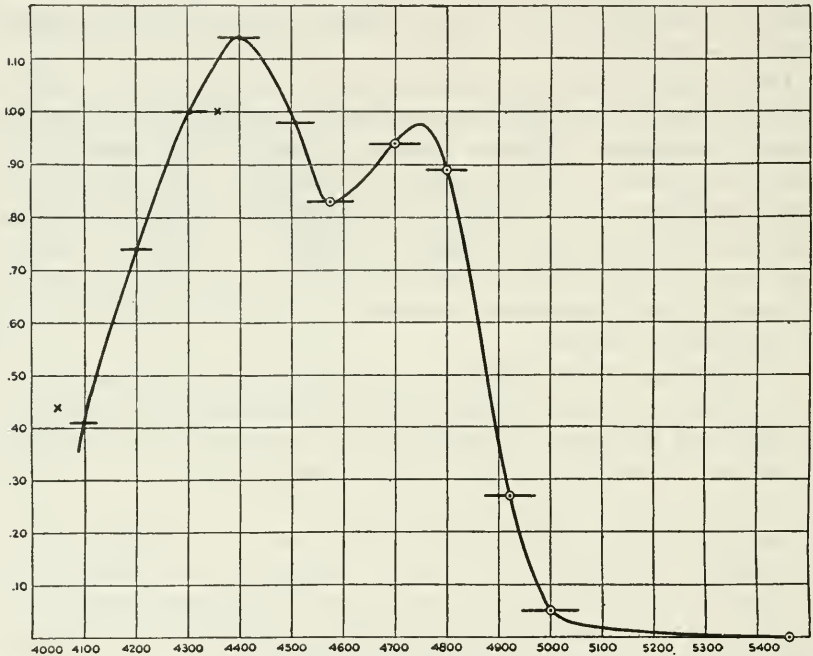
FIGURE 6.—Phototropic sensitivity curve of oat coleoptile. The ordinates are relative sensitivity values, the abscissae wave lengths in angstroms, and the horizontal bars indicate the wave-length ranges of the balance points.

tivity decreases rapidly to 5000 A, from which point it gradually tapers to 5461 A, the threshold of sensitivity on the long-wave-length side. Briefly, it may be concluded that the region of greatest sensitivity is in the blue. That is, growth is retarded most by blue light. Orange and red light have no effect in retarding the growth of these oat seedlings.

An interesting phenomenon closely paralleling phototropism has been observed for a certain type of seed germination. Dr. Lewis H. Flint, of the United States Department of Agriculture, found that the short wave lengths of light—violet, blue, and green—inhibited the germination of light-sensitive lettuce seed, and that the long wave

lengths—yellow, orange, and red—promoted germination. So interesting did these observations prove that he and Dr. E. D. McAlister, of the Smithsonian Institution, carried out a much more elaborate and detailed experiment (Flint and McAlister, 1935, and Flint, 1936). Seeds exposed to red light sufficient to bring about a 50 percent germination had superimposed upon them the prismatic spectrum of a Mazda light. The resultant germination, as influenced by different wave lengths, is shown in the form of a curve in figure 7.

Had the seeds not been exposed to the spectrum, their germination would have been 50 percent as represented by the horizontal dash
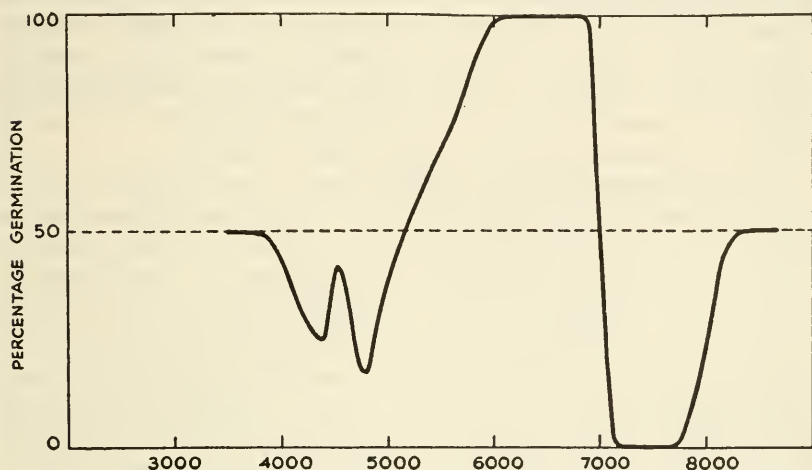
FIGURE 7.—Percentage germination (ordinates) of light-sensitive lettuce seed in different wave-length regions (abscissae) of the spectrum after an exposure to red light sufficient to effect a 50-percent germination. (Courtesy Flint and McAllister.)

line. The germination of seeds exposed to wave lengths lying approximately between 4000 and 5200 A was inhibited. That between 5200 and 7000 was greatly promoted. An interesting and heretofore unobserved phenomenon was found in the red at about 7600 A. Here also germination was inhibited. Although this inhibitory region in the red has not been detected in our phototropic responses, it may have been overshadowed by other effects not yet properly isolated.

Experimentation has clearly demonstrated enormous differences in response of living plant tissues to different wave lengths of radiant energy in the visible spectrum. When such interesting reactions occur in visible light, one becomes curious as to what effects are found with wave lengths shorter than the visible violet and with those longer than the visible red. Time will not permit giving more than a single example in each of these two regions.

The harmful action of ultraviolet radiation is familiar to all; its painful action has been felt by most of us at the bathing beach after

our first "outing" of the season. Its lethal action on micro-organisms has been studied by many experimenters, especially in connection with the treatment of disease. The "scare" headlines of the daily press frequently designate it as the "death ray." Ultraviolet radiation covers a wide range of wave lengths. These different wave lengths have their specific characteristics just as truly as the wave lengths in the visible spectrum.

The Smithsonian Institution has been interested in the specific action of these ultraviolet wave lengths on green algae, one of the lower forms of plant life. Using the variety *Chlorella vulgaris*, Dr. Florence E. Meier (1936) has grown cultures on agar plates and exposed them to the ultraviolet spectral lines of a quartz mercury vapor lamp. The intensities of 20 different wave lengths ranging from 2250 A to 3022 A were carefully measured and their effects studied with respect to their lethal sensitivity and to their radiotoxic virulence or speed of effectiveness in killing the cells.

An algal spectrogram with distinct areas of dead cells is shown in plate 4, figure 2. A photograph of an algal plate exposed to the ultraviolet spectrum has been superimposed on a diagram representing the intensities of the different mercury lines. Three exposures are here shown: (1) 64 minutes, (2) 16 minutes, (3) 32 minutes. The wave lengths are noted across the bottom of the diagram. The heights of the vertical bars represent radiation intensities in thousands of ergs/sec./cm ^{2}. It was from plates and data like these that the radiotoxic spectral sensitivity and virulence were calculated. Dr. Meier (1936) reports maximum lethal sensitivity at 2600 A, and a change of virulence with decreasing wave length, which reached a high maximum at 2323 A.

Let us take a moment to consider a case in the near infrared, just beyond the visible red of the spectrum. In one of our experiments (Johnston, 1932), tomato plants were grown under two sets of wavelength conditions. In one, only visible light was present; in the other, near infrared radiation was added to the visible. Although the near infrared plants were taller and heavier, their appearance was far from normal. A marked decrease in chlorophyll occurred in the leaves and a distinct yellowing and death was noted in some cases. It appears that if this near infrared region is not actually destructive to chlorophyll, it is of little or no benefit to its formation.

In connection with a discussion of ultraviolet and infrared radiation effects, it is interesting to note that in the experiments of Dr. John M. Arthur (1932) at the Boyce Thompson Institute for Plant Research, Inc., on the production of pigment in apples, coloring was increased by ultraviolet radiation, while the near infrared radiation alone or in the presence of visible light had a marked detrimental

effect. Under these rays a typical wrinkled, necrotic area soon develops.

Much progress has been made in our knowledge of sunlight and the manner in which it affects plants. A considerable amount of this information, covering the general field of the biological effects of radiation, has recently been compiled by the National Research Council in two volumes edited by Dr. Benjamin M. Duggar (1936). In order to simplify the problem we have considered sunlight under the effects of its duration, intensity, and wave length. As our experimental science has improved, artificial light sources were used because their variables could be controlled better and the conditions of the experiment repeated fairly accurately. In a last analysis, artifi-
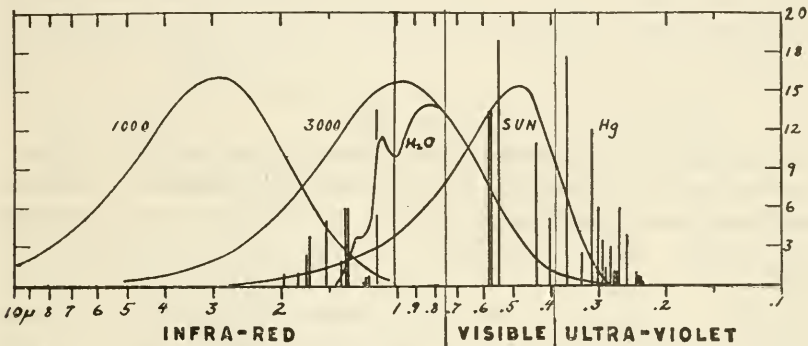
FIGURE 8.—Diagram of relative energy emission curves from a body at 1,000° K. (dull-red therapeutic lamp) and at 3,000° K. (high-temperature tungsten lamp) compared with that from the sun and from a mercury arc in quartz. The type of radiation from a tungsten lamp equipped with a 1-cm water cell is also shown.

cial light is modified sunlight. Duration experiments can be controlled better with artificial light than with sunlight. Although the intensity of artificial light is less than that of full sunlight, yet for many purposes it is sufficiently great. The most vital difference between sunlight and artificial light lies in the quality or wave length distribution. An examination of the curves shown in figure 8 may help make this point clear. Compared with the energy distribution curve of solar radiation are similar curves constructed from tungsten filament radiations at two different temperatures. Attention is called to the position of the maximum of each curve. In the tungsten this is in the infrared, whereas in sunlight it occurs in the yellow. Other artificial lights may likewise be compared with that of the sun. Each shows a characteristic departure from a perfect or even fairly good match. Even filters combined with artificial lights have failed to give the desired similarity. It will be a distinct step forward in this type of research when an artificial light source is developed that has an energy distribution curve similar to that of solar radiation.

Since plants have been growing on the earth for millions of years it is reasonable to assume that their physiology is adjusted best to sunlight. Although there is experimental evidence to show that different processes go on better in some wave lengths than others, yet the exact relationship of each to radiation should be studied separately under well-isolated portions of the spectrum. This creates another problem for the physiologist. Numerous color filters have been made whereby sections of the spectrum are isolated, but with all these filters the regions are not sufficiently narrow for an accurate analysis of the problems. Furthermore, many filters are transparent to wave lengths other than the ones desired, thus making it difficult to interpret the results. Considerable progress has been made in obtaining filters, and some of the difficulties have been removed by the adaptation of the Christiansen filter with its improvements as developed in our laboratory by Dr. McAlister (1935). This is the filter that Mr. Hoover used in his studies on the photosynthesis of wheat in different wave lengths of light.

I wish to call your attention to another possible method of obtaining isolated wave lengths for experimental purposes. Different metallic elements when electrically excited emit light of characteristic wave lengths. This is familiar to all of us in the neon and mercury lights so common at present. For our experimental work with plants it becomes a problem to select the proper elements that will give light of a desired wave length and intensity. One light for which we have a specific need is that given out by the element cadmium. Leland B. Clark, of the Smithsonian Institution, is at present experimenting with the manufacture of this lamp.

With better light filters and with the construction of new light sources it is hoped to break white light into narrower and narrower spectral regions of sufficient intensity to study more accurately the many reactions that take place in the living plant—reactions upon which life itself depends.

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Courtesy U. S. Department of Agriculture.

1. Effect of length of day on Mammoth tobacco grown in greenhouse in winter. Plant on left shows characteristic behavior under a short day length. Plant on right was grown under similar conditions except that the day period was lengthened by use of electric light, which prevented it from flowering.

Courtesy U. S. Department of Agriculture.

2. Yellow cosmos, a short-day plant, grown with equal alternations of light and darkness ranging from 12 hours to 5 seconds. With decrease in the intervals of light and darkness there is progressive decrease in height, size, and weight of the plants and increase in etiolation and attenuation till the 1-minute interval is reached. Further shortening of alternations causes marked improvement in growth and appearance of the plants. All intervals from 1 hour downward are almost equally unfavorable for flowering.

PLATE 2

Courtesy R. B. Withrow.

1. Effect of supplementary artificial illumination on forcing aster (Heart of France) into flowering.

Courtesy R. B. Withrow.

2. Wave-length effects of supplementary artificial illumination on a long-day plant (stock).

Courtesy R. B. Withrow.

3. Wave-length effects of supplementary artificial illumination on a short-day plant (salvia).
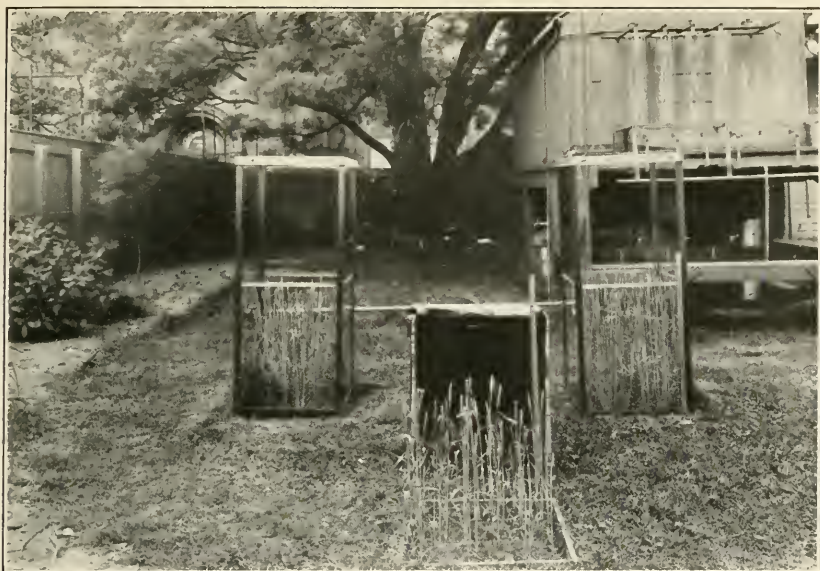
1. General appearance of wheat plots. That in the foreground was open to normal air; the two in the background were enclosed in glass. Carbon dioxide was added to the one on the right.

2. General appearance of wheat at harvest. Average carbon-dioxide concentrations relative to air were A, 3.8; B, 1.1; C, 0.9.
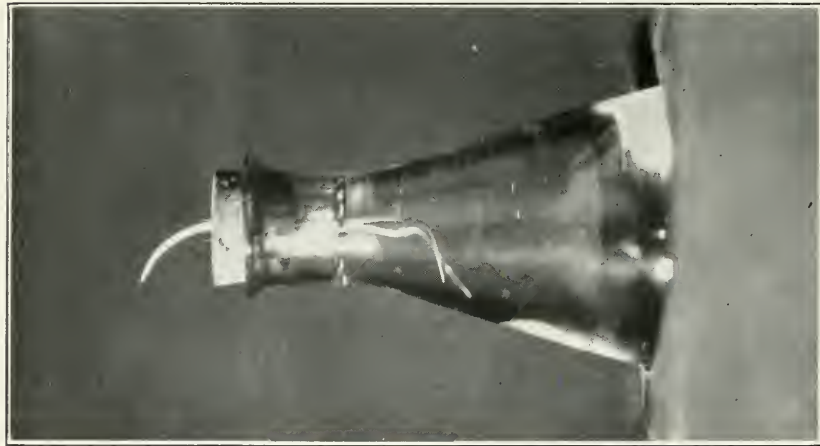
PLATE 4

1. Phototropic curvature of an oat seedling resulting from a difference in illumination on two opposite sides.
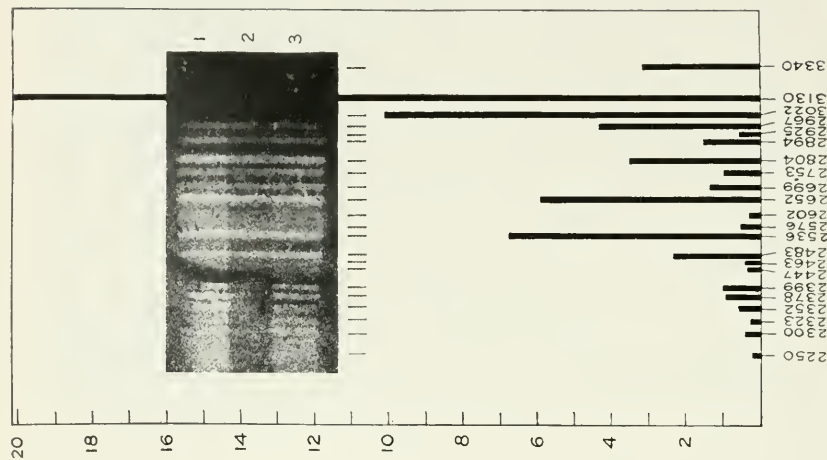
2. An algal spectrogram, obtained by exposing a plate of *Chlorella vulgaris* to ultraviolet radiation from a quartz mercury lamp for (1) 64 minutes, (2) 16 minutes, and (3) 32 minutes. This spectrogram is superimposed on a diagram of intensities (ordinates in thousands of ergs/-

REACTIONS TO ULTRAVIOLET RADIATION

By Florence E. Meier

Division of Radiation and Organisms, Smithsonian Institution

[With 2 plates]

The health-giving power of the sun's rays was recognized long ago in ancient Greece. In the temple of Hippocrates there existed terraces for sun exposure, and Herodotus, in his history, tells of "barbarians" who are covered all over with clothes and have a pale-colored skin and feeble muscles. In the Roman baths there was always a solarium, and Plinius writes in one of his letters that he has been ill and is going to take sun baths for convalescence.

Numerous medieval engravings and miniatures have for their subjects the love of water, air, and light. Then in the seventeenth century, perhaps as a matter of fashion, the bath became a remedy and the value of sunlight was disregarded. It was not until the end of the eighteenth century that a Swiss by the name of Rickly developed a cure for diseases by treatment in the open air and sun baths. Unfortunately, only a few physicians were influenced by his ideas. In the nineteenth century the poet Michelet, seeing children playing on a beach beside the sea in the sunshine, wrote the following sentence, which is startling for his time: "De toutes les fleurs, c'est la fleur humaine qui a le plus besoin de soleil." (Of all the flowers, the human flower most needs the sunshine.)

Quite by accident a hint of the curative action of sunlight was given in the middle of the nineteenth century to physicians at Paris. It was customary at that time for the city of Paris to board sick orphaned children with peasant families in the country in order to prevent epidemics in orphanages. Many were sent to the seashore near Le Touquet, since the cost of living was not high and there was plenty of good milk. A widow named Madame Duhamel was especially successful with the children entrusted to her care. She asked for the most unhealthy children, those crippled or with diseased glands, and after a year of her care they became strong, healthy, and happy. Her method was to carry all the children in a wheelbarrow to the beach every morning where she took off their clothes in order to save them from being soiled and let the children

play all day long in the sunshine. Recognizing the success of her method, the authorities presented her with a few very crippled children and a donkey cart in which she could drive them to the beach. As this experiment proved successful, a large hospital was built on the beach with a good surgeon as director. But the children in the hospital did not improve as rapidly as under Madame Duhamel's care, since they were kept in bed in large rooms and when playing in courtyards their coats were never removed.

Later Dr. Bonnet, in the middle of the nineteenth century, noticed that joint tuberculosis improved by exposure to sunlight. After him a succession of surgeons and doctors noticed the effect of sunlight treatment on patients, until finally sun treatment was adopted everywhere in Europe.

Why is sunlight so beneficial in the treatment of invalids? And why are people who live most of their lives in the open air and sunshine able to build up a great immunity to disease? What is there in the sun's rays that promotes health and well-being?

Beyond Newton's seven visible rays of the spectrum, which may be separated in a sunbeam by a prism, are certain invisible rays which are of vital importance to life on earth. These rays are shorter in wave length than the visible violet rays, so they are called ultraviolet rays. Only a very small quantity of these rays—a trifling percentage of the total—is present in the sunlight that reaches the earth. There is a much larger quantity of them outside the earth's atmosphere, but the ozone formed from oxygen in the upper layers of the atmosphere by the action of these ultraviolet rays serves as a ray filter that protects the life on the surface of the earth from these shorter rays which have been proved to be very destructive to tender tissues.

After the sun treatment, or heliotherapy, had been generally adopted, and since it was difficult to find sunshine in winter in all places, an artificial source of ultraviolet rays seemed desirable to replace the missing sunshine. The quartz lamp is generally used in hospitals under medical supervision for this purpose.

Alfred Hess, who succeeded in explaining scientifically the efficiency of sunshine, noticed that rickets is very frequent among babies born in winter or in the autumn, due to the fact that they are kept indoors without enough sunlight. He succeeded in inducing rickets in rats with a rachitic diet and discovered that they got rickets only when kept all the time in complete darkness, and that, with the same diet, they were protected from rickets if exposed for about half an hour each day to the sun. The rats with rickets, when in cages with rats treated with sunshine, cured their rickets by eating the excrements of the sunshine-treated rats. In other

experiments he observed that rats on a rachitic diet kept in dark-
ness did not develop rickets if they ate the skin of irradiated rats.
He therefore concluded that the antirachitic factor could be ab-
sorbed with the food and that exposure to sunlight was not necessary
as a treatment or prophylactic measure.

Various scientists have shown that sunlight, natural or artificial
(produced by the ultraviolet rays of the quartz lamp), has no effect
on starch, mineral salts, and some other products. Only that food
which contains fats is subject to the action of sunlight. The activ-
able substance in the fat is not the fat itself, but the unsaponifiable
part of the butter, a sterol, and the particular variety of sterol is
called ergosterol. Ergosterol, when preserved in darkness, has no
physiological activity. Only after irradiation with ultraviolet rays
does it become antirachitic in a high degree. Ergosterol is extremely
active in treatment and prophylaxis of rickets in babies and young
children. The treatment is so active that it must be stopped after
a month. As a preventative, ergosterol has the same power. In
certain countries where there is a lack of sunshine in winter, such
as East Prussia, the Government distributes gratuitously vigantol
for the new-born and small babies.

Ultraviolet rays may be used to irradiate babies in order to
rectify the lack in their diet of the elements necessary for making
bone. This irradiation furnishes vitamin D from the provitamin
in the skin. It influences the storage of calcium and phosphorus and
their equilibrium in the blood stream of mature animals in a similar
way as in growing animals. The antirachitic factor, or vitamin
D, is the specific organic agent which promotes normal calcium
metabolism. It may prevent and cure rickets, promote growth, or
simply prevent excessive loss of lime from the body.

All the research that resulted in the activation of ergosterol was,
so to speak, a combining of old observations on the therapeutic value
of fish oils and of light. It has shown that ultraviolet rays acting
on the sterol-bearing fats of the skin produce a form of vitamin
D similar in antirachitic action to the vitamin D contained in fish
oils. The vitamin D produced by the irradiation of pure ergosterol
has recently been obtained in crystalline form. A recent investigator
has found that irradiated cholesterol was many times more effective
on chickens than ergosterol that has been irradiated either by itself
or in the presence of cholesterol.

Vitamin D rarely occurs in living plants. The lower plants that
are not pigmented and do not make their own food thrive in dark
places and perish in the light. The higher plants containing very
little ergosterol possess pigments that filter out the activating rays
at the short end of the solar spectrum.

Recently a new vitamin D with rickets-preventing power has been obtained by irradiating a provitamin from sitosterol, the substance in plants which corresponds to cholesterol in animals.

Vitamin D is widespread in the animal kingdom but is abundant only in the fishes. It has been suggested that it may be formed by the action of the sun on the green algae, which are then swallowed by the little fish and these in turn by the bigger fish. Evidence has thrown some doubt on this supposition, however. Irradiation of the body surface of fish appears to play no part in the formation of vitamin D. Experiments performed by Bills made it appear probable that a portion of the vitamin D in fish originates by synthesis within the fish. The higher animals cannot synthesize vitamin D, so they must either ingest it by eating such food as eggs, fish, whole furred or feathered animals, and insolated dead vegetable tissues, or receive it by exposing the body to sunlight.

Birds, according to the findings of Hou, differ from mammals in having only one gland of a sebaceous nature. This is the preen gland. Preen-gland oil contains ergosterol, which the birds when preening distribute over their feathers and expose to sunlight. The vitamin D is then ingested either by swallowing the feathers or is absorbed by the skin from the feathers. Normal birds have feathers and skin that are antirachitic, but rickety birds or birds whose preen glands have been removed have feathers and skin with little, if any, antirachitic action. When the preen glands were removed, the birds became susceptible to rickets, and rickety birds without the preen gland received no benefit from exposure to ultraviolet irradiation or to sunshine. Nocturnal birds and the carnivorous animals that prey upon other forms of "feather and fur" possibly obtain their vitamin D from their victims. The absence of the oil gland in some birds may be explained in this manner, and it is then necessary to add rabbits or small birds with their fur or feathers intact to the diet of young birds in captivity. It is commonly known that horses when thoroughly scrubbed with soap and water do not thrive. In all these sources of the essential vitamin D it is noted that, with the possible exception of fish, the origin of the vitamin is traceable to sterols that have been activated by ultraviolet light. The skin absorbs the rapidly effective ultraviolet rays so strongly that little, if any, radiation reaches the blood stream.

Recent physiological experiments show that normal individuals seem to have powers of compensation sufficiently great to counteract any stimulation resulting from ultraviolet irradiation.

Skin sensitivity to ultraviolet rays depends on the color of the skin and hair, the age of the individual, and the time of the year when exposure occurs. The pigmentation developing after irradiation

serves as a screen by absorbing ultraviolet energy and preventing its further penetration. Degeneration and ulceration of the tissues may be caused by an excessive dose of ultraviolet. Bathers who expose the surface of their bodies to the sun for hours may undergo blood alterations. Bathers should begin their sunbaths gradually, remembering the aphorism of Hippocrates: "To heat or to cool or in any fashion to trouble the body to excess, or suddenly is a danger-ous thing, for excess in everything is the enemy of nature; but it is prudent to proceed gradually, especially in passing from one stage to another." Forgetfulness or lack of observance of this precept of the father of Naturisme has caused mortal sunburn accidents.

All travelers in the Tropics have heard of the term "tropical pal-lor." It is applied to white people who, in spite of their sojourn in the hottest climates of the tropical jungles, never seem to become tan; in fact, they appear to be paler than they habitually are in the sum-mertime under the sun of their own temperate climate. Recent re-search has shown that human sweat partially absorbs ultraviolet light in the spectral region that is effective in producing sunburn or erythema. The scientists placed a drop of perspiration between two flat plates of crystal quartz which transmits ultraviolet light. They placed this over the inner forearm of one of the scientists and then irradiated it with the total radiation of a quartz mercury lamp. The skin under the quartz plates in time developed normal sunburn ex-cept for the small area of about a square centimeter directly under a 0.2-mm film of perspiration where the reddening of the skin was markedly less than that of the surrounding region. Spectrophoto-metric measurements indicate that a 0.5-mm film of human sweat transmits only about 75 percent of the solar radiation which is ef-fective in producing sunburn. Is it not possible that, in the Tropics where the humidity is so extreme for a continuous period, the skin is protected by perspiration from the ultraviolet rays that produce sunburn normally in people with white skins? When the same scientist exposed the inner side of the forearm covered with rubber except for a small area of about one square inch to a blast of a 40-mile an hour wind in an experimental wind tunnel, the exposed skin exhibited goose flesh, but at no subsequent time was there the slight-est evidence of reddening or chapping of the exposed area of skin. This experiment seems to indicate that ultraviolet is entirely re-sponsible for sunburn but that the action might be intensified by the secondary effects of the wind, such as a variation of the tempera-ture and moistness of the skin, and a suppression of perspiration which, when present, would protect the skin from the ultraviolet rays.

Sun baths are certainly not likely to cause cancer in humans. Cancer is produced in rats after prolonged exposure to ultraviolet either from the sun or a quartz lamp. But rats and man do not respond in the same way to sunlight. The normal habitat of the rat is darkness; therefore it is more sensitive to ultraviolet light than man. One year in the life of a rat is comparable to thirty years in the life of a man. It required on an average about 7 months of continuous irradiation to produce cancerous changes in the rat which would be equivalent to 20 hours of daily ultraviolet irradiation for about 18 years in the case of man.

Of the diseases of the skin, *lupus vulgaris* is the only one on which ultraviolet rays have a specific curative action.

The lethal effect of the ultraviolet on the lower plants such as bacteria, fungi, and algae has been studied by a vast number of scientists. The result of their research has been utilized for practical purposes in food preservation, milk pasteurization, sterilization of operating rooms, the elimination of micro-organisms in drinking water, and for partial sterilization of swimming pools. The wave lengths of the ultraviolet having this lethal effect are those of very short range, from 2950 A to 2200 A, or those wavelengths which are filtered from the sunlight that reaches the earth's surface.

Seed plants, because of their complex organization and their need of visible light for normal growth, are still puzzling botanical workers desirous of learning the true response of the plants to ultraviolet light. The amount of the various wave lengths which plants and plant parts absorb increases the uncertainty of knowledge of the subject. The injurious and destructive action of ultraviolet light on plants has, however, been accurately determined for the wave lengths shorter than those present in solar radiation.

The effect of ultraviolet light on the different physiological processes of plants is being studied just as it is on those of animals. The ultraviolet causes a temporary acceleration of respiration in higher plants. A marked acceleration in ferment action is caused by irradiating yeast cells. Results of investigation on chlorophyll formation in green leaves have so far been somewhat contradictory. For all this work such a specialized development of apparatus and technique is required that progress is made very slowly.

The ultraviolet possesses what seems to be an almost magical power to transform an ordinary, somewhat drab object into a thing of breath-taking beauty. A small stone of calcite subjected to ultraviolet becomes a living rose color; hyalite becomes sea green; fluorite, brilliant blue; aragonite, shell pink; wernerite, bright yellow; and willemite, a dark green. All these stones that we might trample over casually with no thought to their appearance, because ordinarily

there is nothing unusual about them, become gems of glowing beauty when placed in the ultraviolet rays. In the fluorescent minerals some slight impurity exists which is the source of the fluorescent property of the mineral. Pale, minute microscopic organisms such as protozoans and bacteria assume brilliant colors in the ultraviolet rays. As they color differently in the separate rays, and as different species behave differently, their more minute outlines and details becoming more evident, the ultraviolet provides a new method for identification of the different species.

This magic power of the ultraviolet is called fluorescence. When a system is excited by absorbing radiation, photochemists teach us that some of the excited molecules may return to their normal state with the emission of radiation of a different wave length from that which produced the excitation. Teeth, various parts of animal tissue, and certain chemical substances are also commonly known to fluoresce in the energy-rich ultraviolet light.

Fluorescence has been adapted to numerous practical uses with which we are all familiar. Brilliant stage effects are produced by tinting the costumes or scenery with fluorescent substances. Many oils and chemicals exhibit fluorescence, and ultraviolet light is used to detect them, as in testing cloth suspected of being contaminated by traces of lubricating oil from the machines and in detecting forgeries of paintings and documents by exposing differences in the chemical composition of the material used in making the original and the forged copy.

In photochemistry, a complicated and difficult field too involved for discussion here, knowledge of ultraviolet rays has proved useful because the light of shorter wave length which possesses greater energy, is more likely to produce chemical reaction. The decomposition of many complex chemical compounds by ultraviolet rays has been studied by photochemists.

The layman is often confused by the terms ultraviolet light, X-rays, and cosmic radiation. He knows that there is a difference between them, but his idea of the relative position of each in relation to the spectrum is not clear. The X-rays are shorter waves of energy than the ultraviolet, and cosmic rays are even shorter than the X-rays. Ultraviolet rays, as we have seen, are present in sunlight or are produced artificially by a quartz mercury lamp. X-rays are produced chiefly by projecting streams of electrons (the smallest known particles of matter) against blocks or targets of metal. X-rays were discovered in 1895 by Prof. Wilhelm Conrad Roentgen, a Bavarian physicist. When investigating electrical discharges through a vacuum tube covered with black paper, he observed that a fluorescent screen at a distance glowed when the current was

turned on.   By continuing his observations he found that rays of
unknown nature were traveling in straight lines from the discharge
tube and that when solid objects were interposed they threw a
shadow on the screen.   He also observed that these unknown rays
could easily pass through objects of low density such as a wooden
door and that they then could affect a photographic plate, making a
record on it of the internal structure of the object.   Everyone is
now familiar with the practical value of X-rays and is aware of
the important part which they play not only in medical practice
but also in scientific and industrial work.

The existence of cosmic rays was not discovered until 1900.
Physicists found that when gas is enclosed in a hollow steel ball,
rays of some sort pass through the metal shell of the ball and steal
electrons from some of the gas atoms, or cause ionization of the gas.
It was later learned that some of this penetrating radiation was
made up of rays from radium in the rocks of the earth's crust.   The
radium-born rays could be prevented from reaching the interior of
the ball by surrounding it with a layer of lead, just as X-ray treat-
ment rooms are encased in lead to prevent the outward passage of
X-rays.   When the ball was encased in lead, however, numerous rays
of energies much greater than radium emanations and X-rays still
penetrated the interior and ionized the gas.   These are the cosmic
rays now believed to be charged flying particles that cannot be seen
and are known only by their effect.   Although the cosmic rays pour
in on the earth, only the strongest of them can register their existence
inside steel balls at the earth's surface.   Since their discovery,
scientists have been piecing together facts about the cosmic rays and
are especially eager to learn about those in the thin rare atmosphere
where they are most numerous and stronger before they have been
exhausted by the comparatively heavy gases near the earth.   The
stratosphere balloon is the only means by which scientists can as-
cend to the stratosphere, 8 miles above the earth, and measure these
cosmic rays.

Here at the Smithsonian Institution interesting and diversified
experimentation is now in progress.   With the assistance of Mc-
Alister (1933) the following researches in the field of ultraviolet
have been conducted.   Algae have been irradiated with ultraviolet
rays by Meier (1936).   In the regions where the ultraviolet was of
shorter wave length than that found in solar radiation the green
plant cells were killed.   The certainty of the action as well as the
speed of the attack of these rays has been determined.

Friedmann (1935) started interesting experimentation on the
potentialities of the secretion of the preen gland of the house sparrow
and of the starling.   Extract of the preen gland was irradiated with

ultraviolet light and fed to birds whose preen glands had been removed and that were living on a vitamin-D-free diet. None of the birds—neither the controls nor those treated—developed rickets on a diet which produced rickets in young chicks, thus showing the markedly different threshold of reaction to vitamin D deficiency in the different species of birds studied.

Austin H. Clark and Grace A. Sandhouse (1936), observing the attraction to light of wasps kept in captivity since emergence from their nest, made a brief study of their behavior in ultraviolet light. They found that violet and ultraviolet light consistently stimulated the wasps to greater activity than did monochromatic yellow or green light. In white light with a daylight filter to approximate sunlight quality the wasps made an equal response at about one-hundredth of the intensity of colored light.

The beneficial action of ultraviolet light, as evidenced by the importance of the serious effects resulting when plants and animals are excluded from sunshine and artificial light, still holds open a great field of research. With the high perfection of apparatus, methods, and technique now in progress, new research on this subject is eagerly anticipated.

The word radiation appears most often at this time in the work of scientists. Under this name are included all the forms in which energy can be extended into space without material support. Ultraviolet, infrared, visible light, X-rays, radio waves, and many other forms are included in this term radiation. Although nothing seems more simple than a light ray, actually much remains to be learned about it.

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PLATE 1
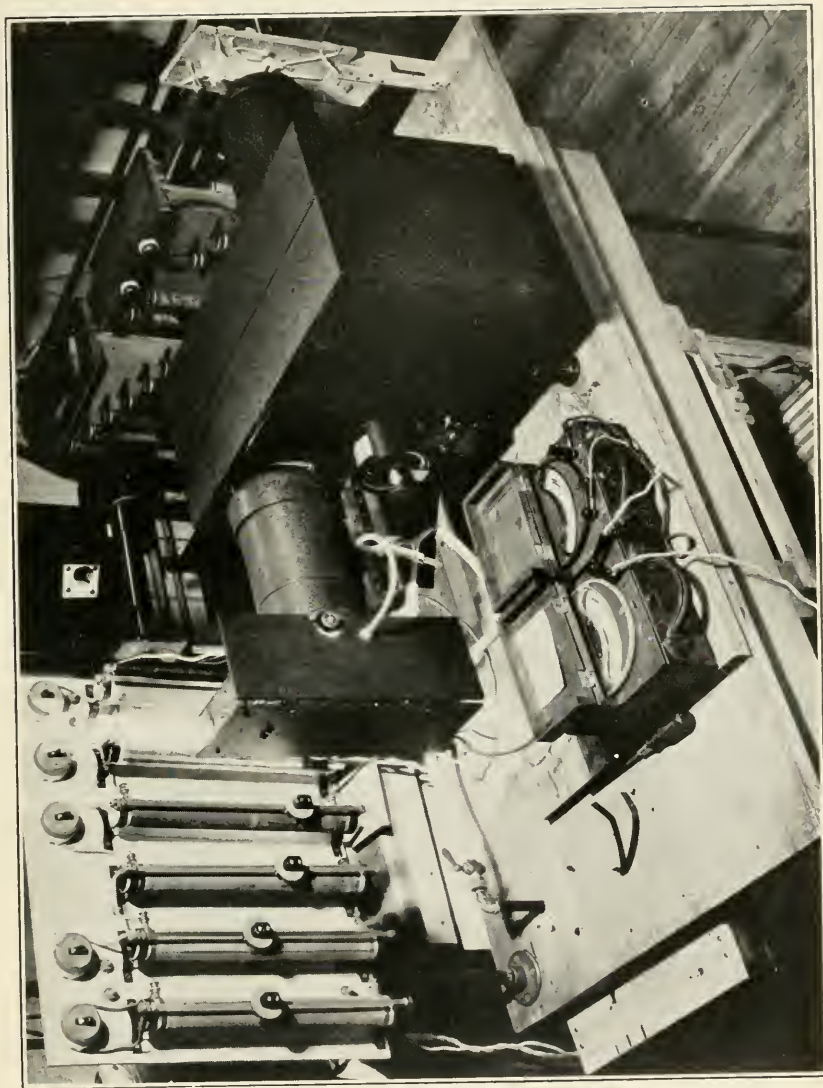
Courtesy of Frank Benford, General Electric Company

AN ANAESTHETIZED RACHITIC RAT RECEIVING ULTRAVIOLET TREATMENT.

PLATE 2
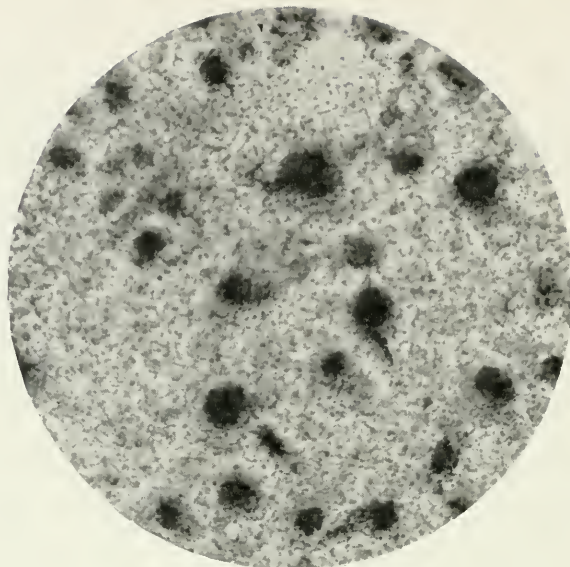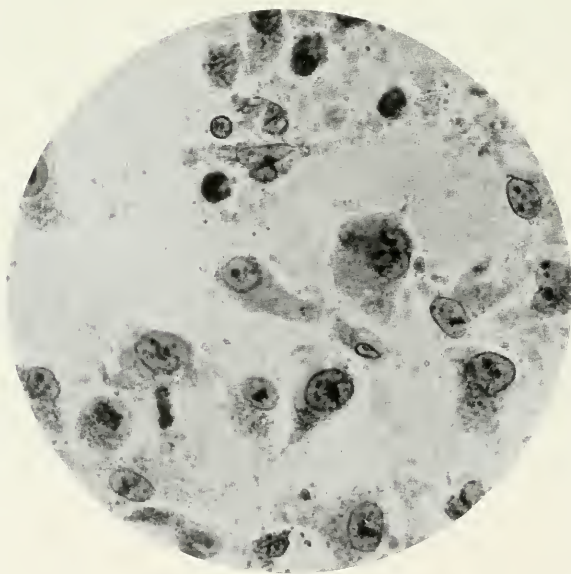
Photomicrographs by Francis F. Lucas, Bell Telephone Laboratories, Inc., New York.

MALIGNANT RODENT TUMOR CELLS PHOTOGRAPHED WITH WAVE LENGTH 2750A BEFORE AND AFTER A 2-MINUTE IRRADIATION PERIOD WITH WAVE LENGTH 2300A.

The irradiation with this wave length has caused the cells to shrink and shrivel almost beyond recognition.

AERIAL PHOTOGRAPHY

By Capt. H. K. BAISLEY
United States Army Air Corps

[With 13 plates]

It is not uncommon to hear a person returning from his first airplane flight remark on how small the fields and towns appeared, or that the earth looked like a carpet when seen from the air. It is a conception of the earth as we know it should be, but one which we have difficulty in getting as we travel about on the ground. It is only natural that the men who pioneered in aviation were impressed by the view obtained while in flight and that they should attempt, by means of photography, to record that view.

EARLY AERIAL PHOTOGRAPHY

In 1861, 42 years before the heavier-than-air flight of the Wright brothers, an oblique aerial photograph of Boston was made by King and Black from a captive balloon at an altitude of about 1,200 feet, and other aerial photographs were made later that day by these same two men as their balloon drifted in a southeasterly direction from Boston. Although considerable information was obtained from this and other photographic balloon flights, the development of aerial photography was slow and its sphere limited to the taking of chance shots until the development of the airplane.

Early work in the development of heavier-than-air craft was entirely an effort to imitate the flight of birds by the mechanical flapping of wings. Attempts at soaring flight came later with the gliding flights of Sir George Cayley (about 1810) and later by Lilienthal, Chanute, Montgomery, and others, and promise of airplanes of man-carrying ability was shown in the one-fourth size engine-driven model aerodrome flown successfully over the Potomac by Samuel Pierpont Langley in 1896.

The successful flights by the Wright brothers in 1903, followed shortly by other flights in this country and abroad, led to the rapid development of airplanes capable of carrying passengers and equipment. By 1911 several airplane photographs had been made, one at College Park, Md. (pl. 1), near Washington, and one of a fire at

383

Salem, Mass. (pl. 2) which is claimed to be the first airplane photograph to be used as a newspaper illustration.

DEVELOPMENT OF THE AERIAL CAMERA

Airplanes are supported by a stream of air passing by the airplane's wings, and as you sit in an open cockpit airplane in flight you find yourself in a very strong wind due to the airplane's motion through the air. This wind seriously interferes with the taking of pictures and has led to the use of cabin airplanes for photographic work, almost to the exclusion of the open cockpit type, and since stability and good visibility in all directions are desired for photography, airplanes possessing these characteristics have been designed. Probably the best of these is the Fairchild monoplane known in the Army as the C–8 (pl. 3, fig. 1).

The rush of air and the vibration of the machine itself makes the use of an ordinary camera for the taking of pictures from an airplane almost an impossibility. Even in the early airplanes, which flew at speeds of approximately 40 miles per hour, the rush of air was enough to collapse the camera bellows or carry them away, and the flimsy construction of the camera allowed the lens to vibrate, owing to wind or the vibration of the airplane, so that a sharp, clear picture was rarely obtained. Early types of aerial cameras are shown in plate 4.

To overcome these difficulties cameras were designed especially for aerial use. They are rigidly constructed fixed-focus cameras with large lenses. Focal plane shutters were used at first, and the pictures were taken on glass plates. The later aerial cameras have shutters set between the lens elements. These have the advantage of exposing the entire plate at the same time, thus reducing the distortion in the picture due to the motion of the airplane during the time the exposure is being made. Owing to its lighter weight, most aerial cameras now use film instead of plates.

Because of the limited angle of view which one lens will include and the desirability of photographing large areas without an excessive amount of flying, multiple-lens cameras have been designed. These include two-, three-, four-, five-, and nine-lens models. The equipment necessary for printing these pictures is as elaborate as the camera itself. The shutters of these multiple-lens cameras, which are tripped either mechanically or electrically, must be carefully synchronized so that they will all trip at the same instant. The five-lens camera has an angle of view of approximately 140°, which will photograph a strip of territory a little over five times as wide as the altitude at which the airplane is flying. In flying at an altitude of 25,000 feet photographs are obtained of a strip of land ap-

proximately 25 miles wide. From these photographs features can be plotted on a map probably more accurately, and certainly much more rapidly, than can be done by ground survey methods.

The pictures taken for mapping purposes are the kind ordinarily called "still" pictures to differentiate them from "moving" pictures. These pictures are taken at intervals during flight, varying from a few seconds to several minutes, depending on the altitude and speed at which the airplane is flying as well as on the area covered by each picture. Most mapping processes require that all parts of the area to be mapped show on at least two photographs, and this requirement, together with the conditions outlined above, determines the time interval between exposures.

At the present time there are in use in this country two types of cameras that are considered to be up to date. One of these, the K3-B (pl. 5, fig. 1), which is a single-lens camera using a lens of 8¼, 12, or 24 inches focal length, is electrically operated and can be set to run automatically, taking pictures at a predetermined interval of anywhere between 3 or 4 seconds and several minutes. It can also be manually operated and is adapted to both vertical and oblique photography. The picture size is 7 by 9 inches. The other, the T3–A (pl. 6, fig. 1), is suitable for mapping purposes only and is manually operated. It has five lenses, taking five pictures simultaneously. A contact print is made from the negative exposed in the central chamber, and the other four are printed through a transforming printer. The final five prints are assembled as a single vertical photograph as shown in plate 11, figure 2. The picture taken with this camera measures 30 inches across.

PICTORIAL PHOTOGRAPHY

Aerial photography is divided into two broad classes, known as verticals and obliques. The former class comprises photographs for which the axis of the camera is held as nearly vertical as possible at the instant of exposure, and the latter class includes all other photographs.

Oblique aerial photographs were obtained from kites and balloons long before the invention of the airplane, and the earliest airplane photographs also were oblique views. They have the advantage of presenting a view as we are accustomed to seeing it, and accordingly they convey information that would be overlooked in the unnatural view afforded by the vertical photograph. Examples of obliques are the pictures of San Blas Island and of Irazu volcano and other mountains shown in plates 7 and 8. These pictures are useful in mapping work as well as being of scenic beauty. The photographs of the United States Army-National Geographic Society stratosphere

flight of 1935 shown on plate 9 are examples of photographs useful in recording an event.

Oblique photographs give a view very similar to that which we ordinarily observe as we walk about in a flat field, except that a great deal more is included in the view. As we increase the elevation from which we look at the landscape, its aspect changes and the silhouette of hills and other forms of relief against the horizon disappear. Instead of seeing the hill ahead of us, we are more impressed by the rivers, farms, woods, and cities which from lower altitudes of observation are hidden. The camera brings back a record of what we see, and as the height from which the pictures are taken is increased, the area included in the picture increases, also the things hidden by relief become less. The area covered in any single oblique from high altitude is very large. Features such as roads, railroads, woods, streams, cities, and cultivated fields show up distinctly. A little study will also give a fair idea of relief, which is indicated by the drainage and by shadows. However, it is easy to be deceived by the relief actually present when one is studying an oblique picture even though it is more clearly indicated in this kind of picture than in the vertical. Stereoscopic pairs of either obliques or verticals are far superior to single pictures for a detailed study. Besides showing many things which would not ordinarily be observed from an airplane, photographs show features which are not visible to the eye. This is partly because the resolving power of the camera lens is much greater than that of the eye, as is well borne out by photographs taken during the 1934 and 1935 stratosphere flights and by statements of members of the crews of those balloons. Captain Anderson tells me that when at an altitude of about 60,000 feet over northwestern Nebraska he had great difficulty in locating a railroad shown on the map, the position of which was accurately known by him. He finally succeeded in locating it visually by being able to see some cuts through which it ran, although he was unable to see the railroad itself. He also found that farm buildings were invisible, although the different fields and pastures, as well as the smaller plots in which the farm buildings were located, could easily be seen. These railroads and farm buildings are visible on pictures taken from the balloon while at or near its maximum altitude. This is in keeping with observation from much lower altitudes. In the training of airplane observers for the control of artillery fire, puff targets are used. These are moved about by the men of the ground crew which operate them, and the men can be seen moving around with the puff targets when flying at less than 4,000 feet above them but are invisible from higher altitudes.

THREE-DIMENSIONAL PHOTOGRAPHY

Experiments indicate that depth perception or binocular vision disappears at about 500 feet, and that when we look at more distant objects we get no more information by observing with two eyes than we do by observing with one. In observing the actions of people blind in one eye we see illustrated another method of depth perception. Such a person will move his head from side to side and so get slightly different views of what is in front of his eye, and he is thereby able to estimate distances; thus he has, in fact, depth perception of a kind.

In flying an airplane we move rapidly along, so that even at high altitude we get different views or a changing view of the same scene, and we thereby get considerable depth perception, just as the man blind in one eye gets it by moving his head, but the third-dimension sense of depth is not nearly so striking when obtained in this manner as it is when brought out by observing stereoscopically two photographs of the same area taken a considerable distance apart.

By taking aerial photographs in stereoscopic pairs, depth is added to the picture, and it shows up as a visual model in its three dimensions even more strikingly than the scene itself when observed from an airplane. Photographically the two scenes, as observed by the two eyes, can be and often are separated by a distance of several miles. When observed in a stereoscope these two pictures of the same territory taken from a fairly high altitude and a considerable distance apart form a single visual model, which it is only possible for us to approximate when viewing the terrain itself because of the close spacing of our eyes and the inability to carry the image in the mind for any appreciable time as we move along in flight.

THE USE OF PHOTOGRAPHY IN MAPPING

Single lens vertical pictures are useful individually as maps or collectively for the preparation of maps, either photographic mosaics or maps of the conventional kind. A single picture taken with an 8¼-inch lens from an altitude of 21,780 feet will give a scale of 2 inches=1 mile, so that a picture of the size taken by our standard camera, that is, 7 by 9 inches, will include 14¾ square miles and, if used intelligently, can very well serve the purpose of a map of the area shown.

A great many photographs of this type are required by the Air Corps and by the Corps of Engineers for use as maps. They have the advantage of being very cheap in comparison with a map of such an area made by ordinary means. They also contain much more detail than does a conventional map and have the advantage of being

up-to-date throughout at the instant that the exposure is made. They are also free from gross errors in position of objects about which information is desirable.

The vertical photograph, even though it should happen to be taken with the camera truly vertical, will not give an absolutely true plan view of what is in front of the lens unless that subject happens to be absolutely level and without relief. The relief causes distortion in the photographs, which can be accurately computed if the difference in elevation between the various parts of the photograph is known. This distortion, due to relief, makes possible the visualizing of relief when two nonidentical photographs of the same subject are viewed stereoscopically. This is made use of in stereoscopic mapping machines, and also in the mathematical method of determining relief from distortion in overlapping vertical photographs. However, in a single photograph or a mosaic map, this distortion exists as an error in the location of the object. Also the single photograph fails to fulfill all the requirements of a map in that it does not accurately show relief. A person who has studied vertical photographs knows that relief is indicated in other ways. For instance, we know that streams follow the lowlands and that their tributaries become smaller and finally disappear as they approach divides. Also, if a photograph is held in such a way that the shadows on the photograph fall toward the observer and the observer then stands facing the light, a visualization of relief of a kind is realized.

MOSAIC MAPS

Mosaics are two or more overlapping vertical photographs so cut and fitted together that they form one composite picture of the area they cover. In addition to the errors in each individual picture, a mosaic contains errors due to fitting the photographic prints together.

The making of large mosaics and of conventional planimetric maps from photographs is the work of civil engineers, and although it requires some changes from the methods used in making a survey on the ground, the principles are in general the same, and the work is carried on in a manner very similar to that used in plane-table surveying.

CONVENTIONAL MAPS

In order accurately to show relief on maps, the use of contours has been generally adopted. These contours or lines of constant elevation can be plotted from photographs so taken that every point shows on at least two overlapping pictures. Of the methods developed, the only practical ones are those making use of stereoscopic vision. This requires that the two eyes each see the same object but

from a slightly different position. As these pictures are taken from different positions, there results an apparent displacement of objects of different elevations in one picture when compared with the same objects in another picture. From these displacements the differences in elevation between different objects is determined mechanically when such overlapping pictures are observed in stereoscopic plotting machines such as the multiplex or aerocartigraph.

The multiplex (pl. 10, fig. 1) is a plotting machine in which separate projectors similar to the ordinary magic lanterns used to amuse children are held on a frame work in a position which simulates that occupied by the aerial camera at the instant the picture was made. By means of a simple optical device the operator sees with one eye one picture projected on his drawing board and with the other eye the overlapping adjacent picture. The result is a visual model in three dimensions which can be rapidly drawn as a contoured map. The aerocartigraph (pl. 5, fig. 2) is a more complicated instrument for accomplishing the same end and produces results of a considerably higher degree of accuracy.

The rapidity with which aerial mapping can be accomplished is best shown by examples. In the summer of 1936, in order to study all the area within a radius of 18 miles of the center of Washington, the photographic detachment at Bolling Field, D. C., was told to prepare a mosaic map 36 miles in diameter with the center of the District of Columbia as its center. This area was photographed with one airplane during two consecutive days, requiring only 11 hours of flying to photograph the entire area. All the laboratory work, consisting of developing the film, printing, laying, and copying the mosaic was completed within 10 days, and copies of the mosaic map (pl. 11, fig. 1) were delivered within that time. This was all single-lens camera work, done with an $8\frac{1}{4}$-inch focal length K3–B camera from an altitude of 15,000 feet. This kind of photography requires a great deal more time to perform than does the multiple-lens photography (pl. 11, fig. 2) used in the preparation of conventional maps.

Examples of vertical and oblique aerial photographs of Washington, D. C., are shown in plate 12.

The entire State of Massachusetts was photographed to a scale of approximately 1 to 40,000 in 4 days of flying with a five-lens T–3A camera. The preparation of topographic maps from these five-lens pictures probably will not be completed for several years.

DEVELOPMENT AND TREND OF AERIAL PHOTOGRAPHY

The Matériel Division at Wright Field, working in conjunction with camera manufacturers in this country, have produced some

excellent aerial cameras. The development of these cameras has been along two general lines: First, the development of cameras suited to the producing of mosaic maps of a convenient scale or for making oblique views; and, second, the development of a camera for mapping purposes in which the coverage of a large area is desirable and the recording of the detail as shown in a mosaic is not necessary. These second cameras are of the multiple-lens type.

The development of aircraft permitting flight at higher altitudes and the development of wide-angle lenses is tending to change both types of cameras. The single-lens camera may require a longer focal length lens to produce contact prints of a scale usable for mosaics from the altitude at which the airplanes are beginning to fly regularly, and in this case a larger picture should be taken to reduce the flying time to a minimum. In the case of the mapping cameras, the development of extremely wide-angle lenses promises to give a single picture including such a wide angle of view that it will cover as great an area as the usable part in the pictures taken with the five-lens camera. When this point is reached the necessity for a camera with more than one lens will no longer exist.

PLATE 1

College Park from Army Wright. 1911

1102

Lt. Kelly, Curtiss, Lt. Paul Beck, Lt. T. G. Ellyson, Lt. Walker.

9039 A.S.

AN AIRPLANE PHOTOGRAPH TAKEN AT COLLEGE PARK, MD., IN 1911.

PLATE 2

AIRPLANE PHOTOGRAPH OF A FIRE AT SALEM, MASS., TAKEN IN JANUARY 26, 1914, SAID TO BE THE FIRST AIRPLANE PHOTOGRAPH TO BE USED AS A NEWSPAPER ILLUSTRATION.

1. FAIRCHILD C-8 PHOTOGRAPHIC AIRPLANE.
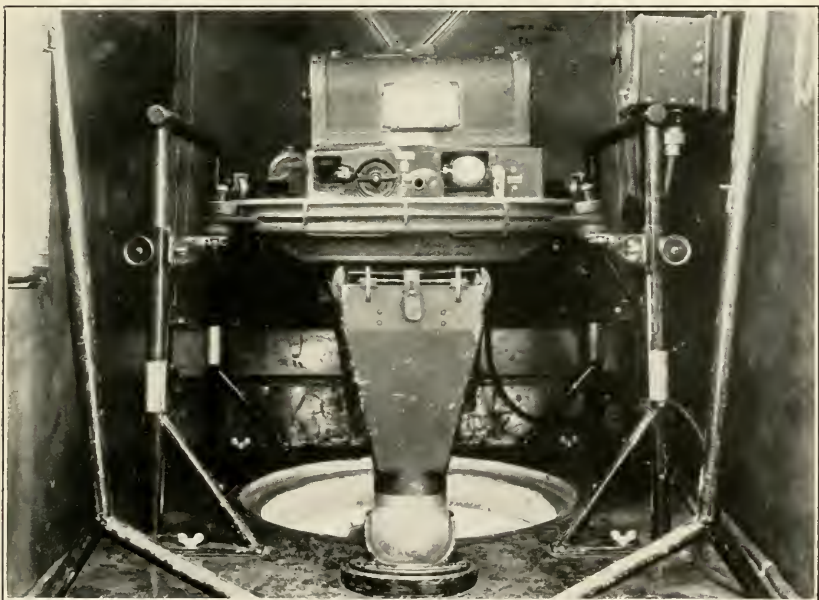
2. K–3B AERIAL CAMERA INSTALLED FOR VERTICAL PHOTOGRAPHS.
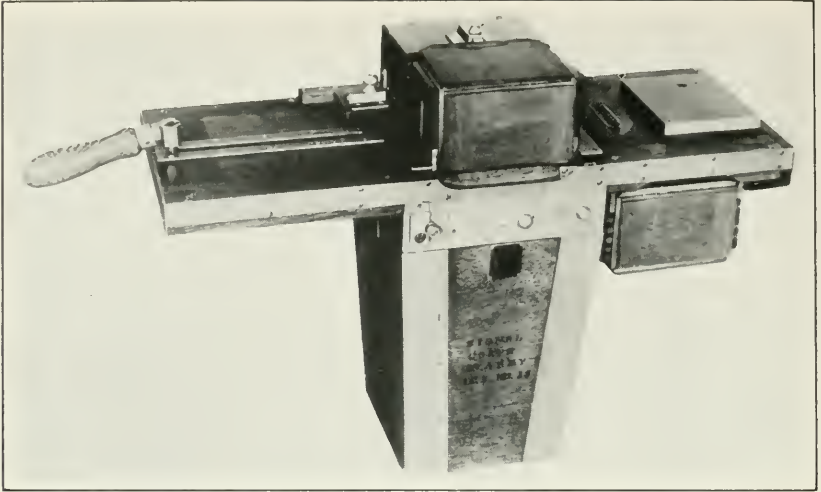
Photograph U. S. Army Air Corps.
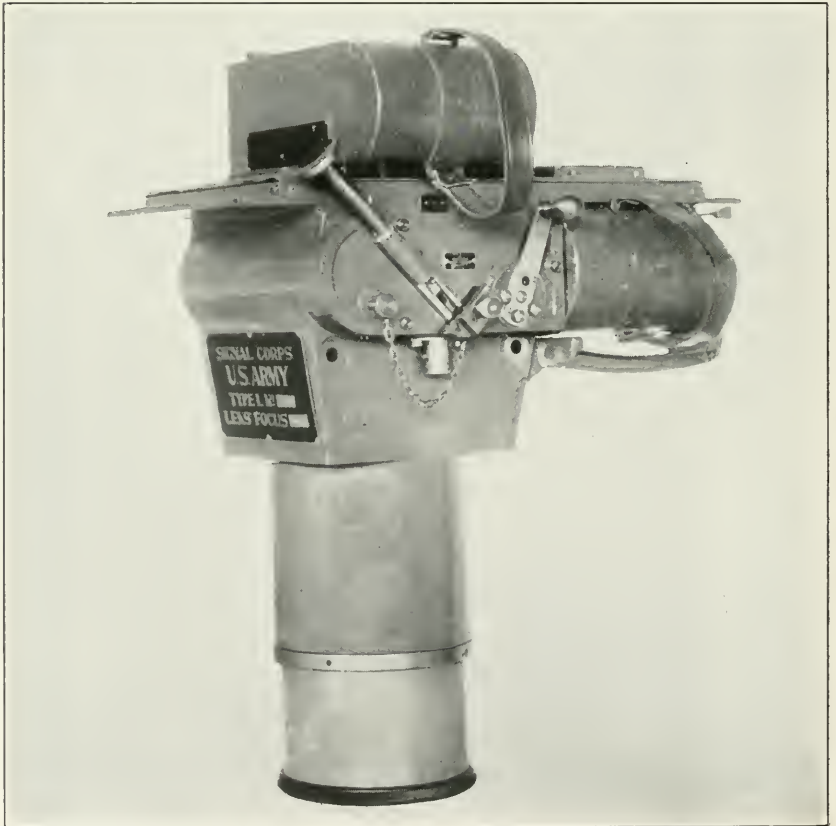
Photograph U. S. Army Air Corps.

EARLY TYPES OF AERIAL CAMERAS.

1. TAKING OBLIQUE PHOTOGRAPH WITH K-3B CAMERA.
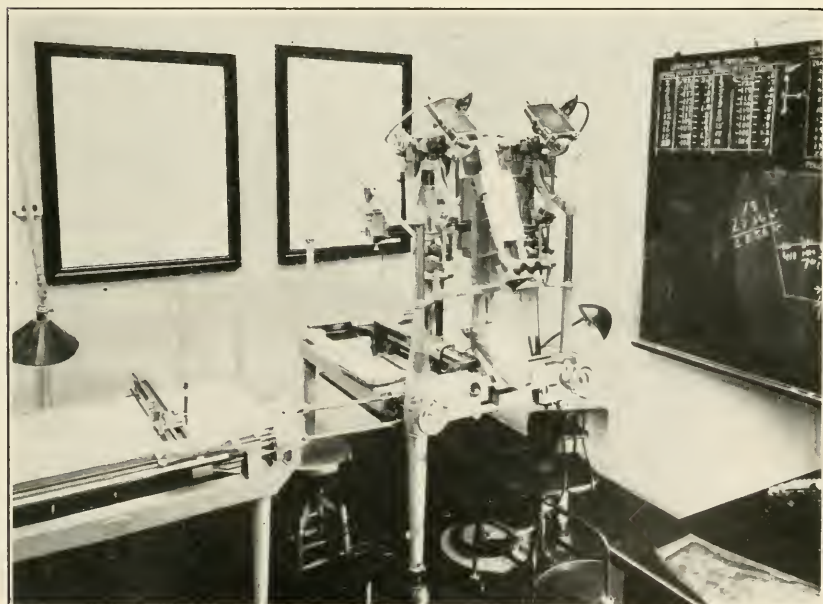
2. AEROCARTOGRAPH, OBLIQUE POSITION.
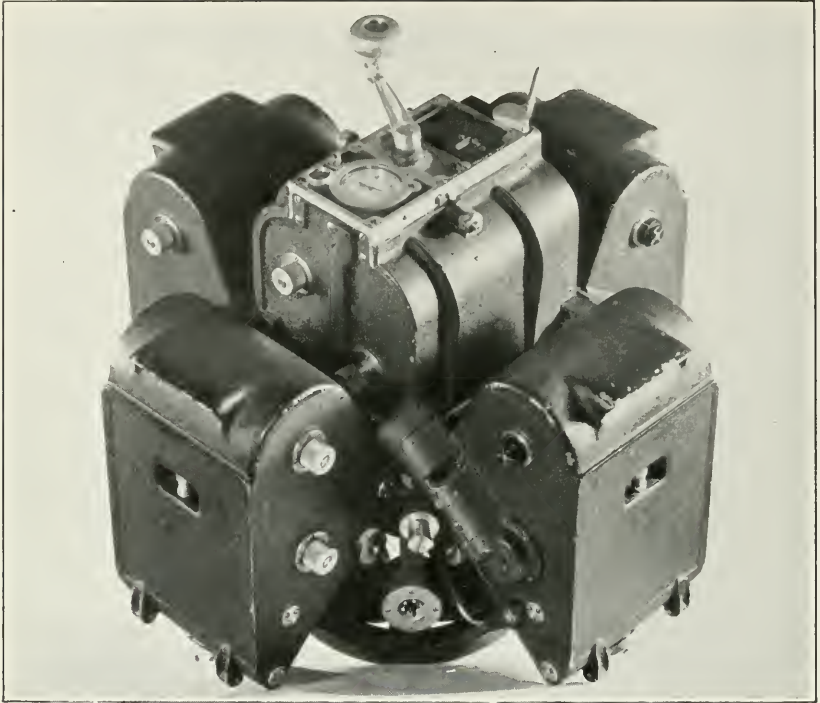
Photograph U. S. Army Air Corps.

1. THE T-3A CAMERA, SUITABLE FOR MAPPING PURPOSES ONLY AND MANUALLY OPERATED. IT HAS FIVE LENSES AND TAKES FIVE PICTURES SIMULTANEOUSLY.
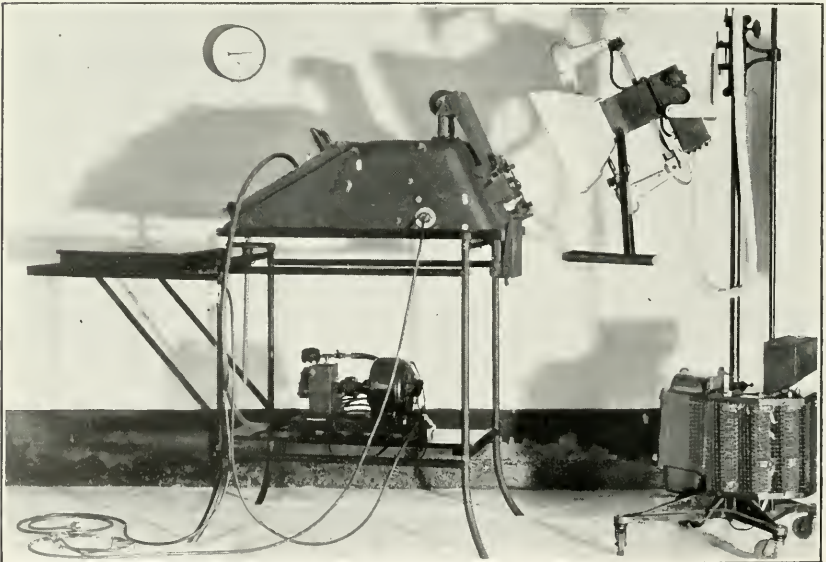
Photograph U. S. Army Air Corps.

2. A TRANSFORMING PRINTER.

PLATE 7

Photograph U. S. Army Air Corps.

1. IRAZU VOLCANO, COSTA RICA.

Photograph U. S. Army Air Corps.

2. SAN BLAS ISLAND, PANAMA.

PLATE 8

1. SOUTHWEST SLOPES OF CHIRIQUI VOLCANO, PANAMA.
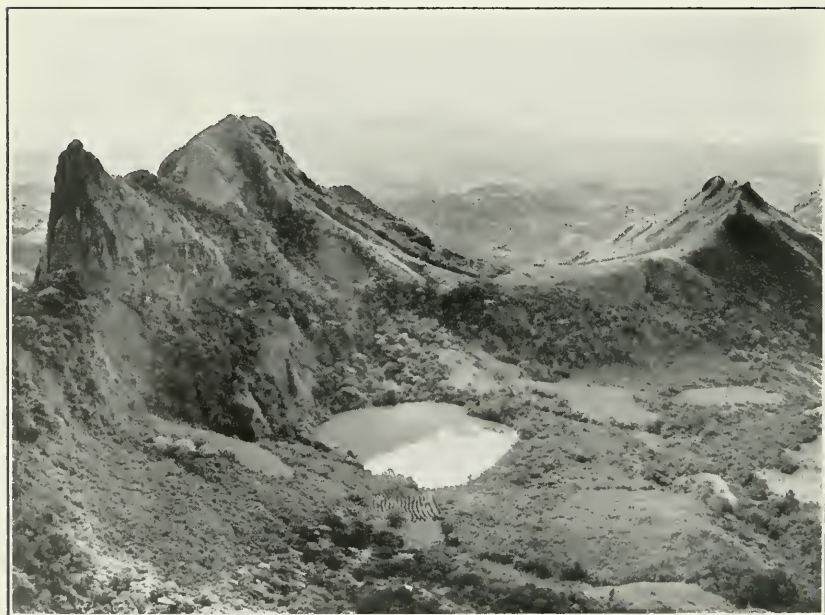
2. MOUNTAINS AND POND, PANAMA.

PLATE 9
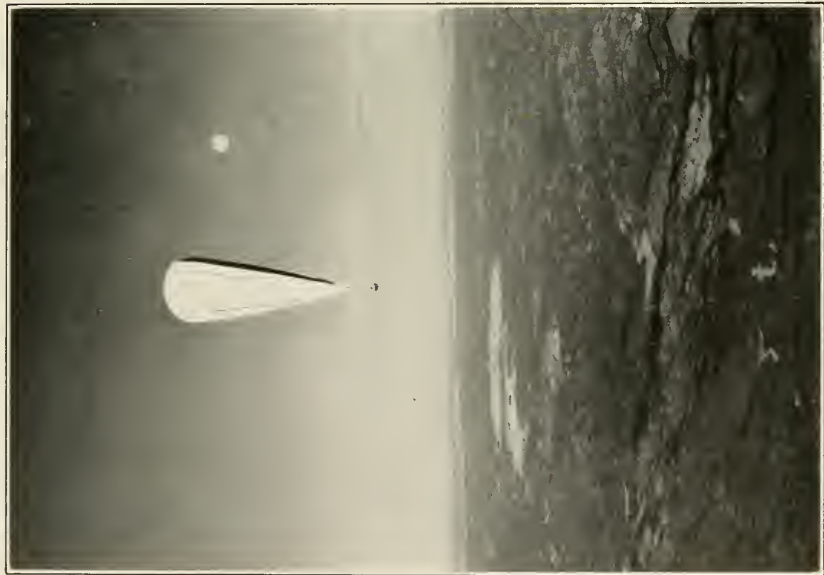
Photograph U. S. Army Air Corps.
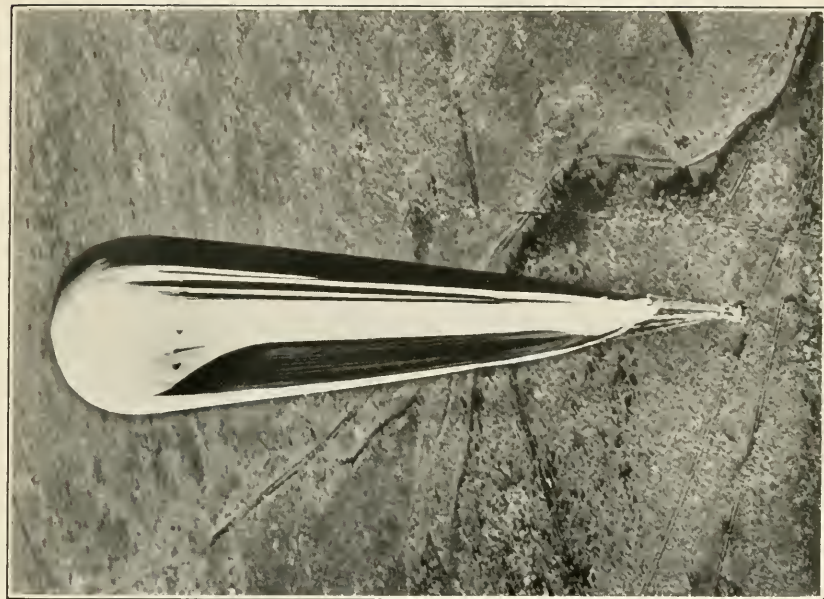
Photograph U. S. Army Air Corps.

TWO PHOTOGRAPHS OF THE UNITED STATES ARMY-NATIONAL GEOGRAPHIC SOCIETY STRATOSPHERE FLIGHT OF 1935.

PLATE 10
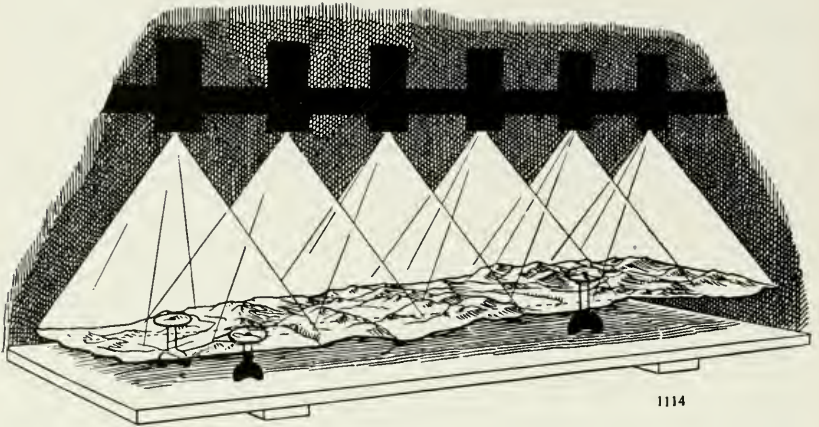
1. SCHEMATIC DIAGRAM OF MULTIPLEX.
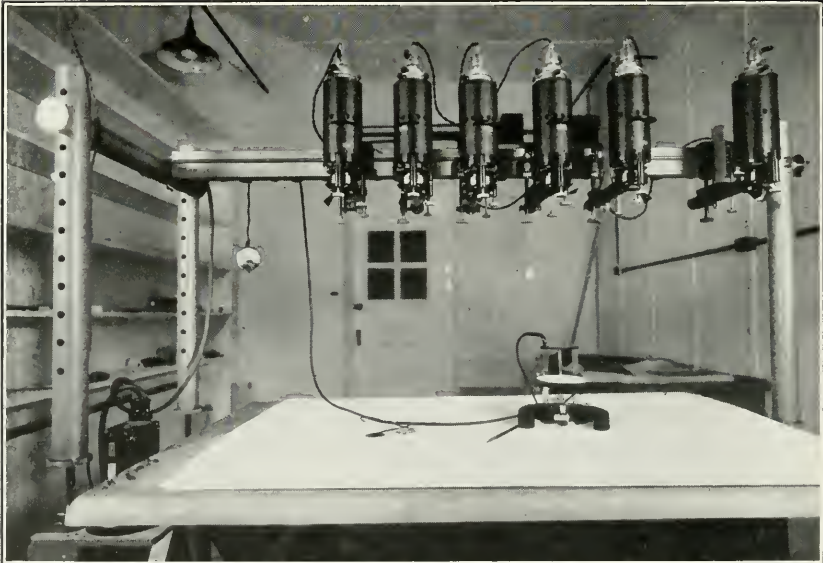
2. THE MULTIPLEX.

Photograph U. S. Army Air Corps.

1. MOSAIC MAPS OF WASHINGTON AND VICINITY, 36 MILES IN DIAMETER.

Approximately 900 aerial photographs, size 7 by 9 inches, were used in the making of this map. This map measured approximately 8 feet in diameter, and was prepared at a scale of 1 to 25,000.
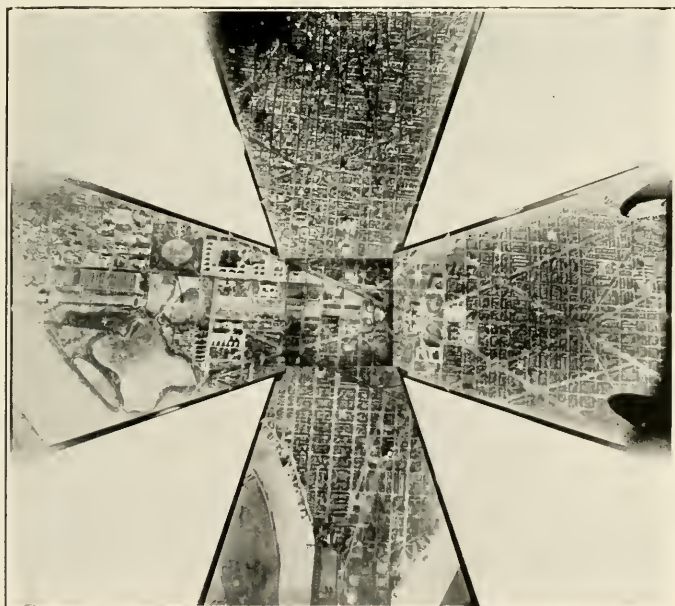
Photograph U. S. Army Air Corps.

2. PICTURE TAKEN WITH T-3A CAMERA.

The center part of the picture is a contact print and the four keystone-shaped prints surrounding it are printed in the T-3A transforming printer shown in plate 6, figure 2.

Photograph U. S. Army Air Corps.

1. AN OBLIQUE PHOTOGRAPH OF WASHINGTON, D. C.

Photograph U. S. Army Air Corps.

2. A SINGLE VERTICAL PHOTOGRAPH OF A PART OF WASHINGTON, D. C.

Taken August 23, 1935, with an 8½-inch focal length lens in a K-3B camera from an altitude of 18,000 feet.

PLATE 13

Photograph U. S. Army Air Corps.

MUNICIPAL AIRPORT AT CINCINNATI, OHIO, DURING THE FLOOD OF THE WINTER OF 1937.

The men on the roofs of these buildings were not seen from the airplane taking the pictures and it was not known that they were there until the pictures were developed and printed. In examining this picture the night it was taken, it was noticed that a man was on the hangar roof, and a telegram was sent to the authorities in Cincinnati. A motorboat was sent out and five people were rescued from the roofs of these buildings.

EASTER ISLAND, POLYNESIA [1]

By Henri Lavachery [2]
Royal Museums of Art and History, Brussels

[With 4 plates]

Few places in the world have given rise to more fantastic speculation than this volcanic island, 70 square miles in area, lying in the Pacific Ocean, lat. 27°10′ S., long. 109°20′ W. Actually the so-called "mysteries of Easter Island", or rather the explanations which have been offered, are not the work of trained men of science. It is natural that the huge statues, standing erect as they do in a naked landscape against a background of black and yellow, should have appealed to the poetic imagination. But those who wish to face with candor the problems presented by certain parts of the world may well be annoyed when the poets' lyrical love of mystery becomes the starting point of speculation. The best students of Easter Island have always told us that it was Polynesian and could only be explained by Polynesia.[3] The evidence that we have now obtained is merely an addition to what was already a formidable pile. Nevertheless we expect that before long others will come forward again with tales of a lost continent of Lemuria, submerged beneath the waters of the Pacific; and that Easter Island is one of its peaks, peopled with Lemurian idols!

For geologists are in complete agreement upon this point. If a Pacific continent existed, it was long before the advent of man and

[3] Routledge, Mrs. Scoresby, Mystery of Easter Island, 1919.

in a part of the southern ocean far removed from that in which the gaunt cliffs of Easter Island confront the unceasing assault of the waves. It is surrounded by vast ocean depths which occur in the expanse of 2,500 miles of ocean separating the island from the American coast on the east and from the nearest land 1,750 miles to the west, namely the Gambier Islands. Easter Island is a volcanic island, and a lofty one, like the Marquesas and Hawaii, in contrast with atolls and coral islands which are low-lying. If one could denude such islands of their dense coverlet of mango-scrub, breadfruit trees, bamboo and cocoa palms, drain the springs, and cover them with a growth of yellow herbage—then such an islet as Hivaoa of the Marquesas will come to resemble Easter Island.

It is the bareness of Easter Island, the result of its colder climate and exposure to the four winds of heaven, which has given birth to these misconceptions. The idea of Polynesia does not fall in with a barren rocky landscape, monotonous pampa, or a pale sun incessantly obscured by rain-clouds.

These talkative Pascuans,[4] like naughy laughing children, whose language and appearance is Polynesian without a shadow of doubt, can no longer be denied those ancestors who carved the notorious statutes, engraved the puzzling symbols of *rongorongo* and set up round the island's coast all those innumerable monuments (actually 184).

At what date was Easter Island first settled? There are excellent reasons for believing that it was between the twelfth and thirteenth centuries of the Christian era. We have certain traditions relating to the peopling of Hawaii and New Zealand. The Polynesians established themselves there at the end of their migrations between the eleventh and thirteenth centuries. Considering the remoteness of Easter Island, it is reasonable to suppose that it was peopled about the same time. The approximate date of the colonization of this island is, however, based upon the list of the Pascuan kings. This list has been narrated to several observers; the most complete is that of Thompson[5] who obtained it from an informant who was a survivor of the pagan period. One may assume a length of 12 years for the reigns of each of the 57 kings in the list. Maurata, the last Pascuan who was certainly regarded as a king, died in 1864, as a result of the Peruvian slave raids. Calculation gives us exactly the beginning of the thirteenth century.

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[4] We may well adopt the English equivalent to avoid the clumsy "Easter Islanders."— Translator.

[5] A paymaster of the American Navy, and the author of a short archeological account which, considering that it was based merely upon a visit of 8 days, is remarkably informative and full. (Rep. U. S. Nat. Mus., 1889, pp. 447–552, 1891.)

But how can one account for the achievement of such a long journey? The Polynesians possessed vessels that could face the open sea; they were capable of taking sometimes more than 100 oarsmen and passengers. Further, they put to sea in squadrons. The canoes kept just as far apart as was possible without losing sight of each other. At night they came together. By thus distributing themselves over the surface of the sea they were able to discover even the smallest islands. Some canoes were lost, but there were enough to ensure that some should reach their objective. Navigation was by the stars, according to the direction of ocean currents and as the wind allowed. But in the Pacific there are regular winds in each season.

Whence came the Pascuans? Every indication points to the Gambier Islands. The similarity of the Mangarevian and Pascuan languages is a valuable clue. Then the Gambier Islands contain ancient monuments which call to mind the *ahus* more than do any of the other *marae* of Polynesia. Father Honoré Laval, in an unpublished account [6] giving valuable information about the ancient culture of the Gambier Islands, speaks of statues resembling those of Easter Island. Finally, the Gambier Islands are those which are nearest to it on the west. The Polynesians probably found Easter Island devoid of monuments and uninhabited; but this statement lacks proof.

The present Pascuans would appear, then, to be the direct descendants of the architects and sculptors of the ancient monuments. Proof of this is to be found in a comparison of these monuments with those of other Polynesian islands. One must also cite the traditions current at the time of the first contact with white men, in which the names of sculptors and of their direct descendants were mentioned.

But there are also certain obvious facts of a common-sense kind. Many of the traditions relate to the construction of *ahus* at a very recent date. Now the statues were merely accessory to these burials— the images of ancestors set up there. If the monument is of recent date, that which adorns it will naturally be so too. Then again, the evidence of the first foreigners to arrive is in agreement; the *ahus* were in living use at the end of the eighteenth century and were seen by Gonzales and La Perouse. We collected traditions reporting that ceremonies were held there still during the nineteenth century.

There is no evidence of the existence of two cultures. Up to quite modern times, when the *ahus* were being made and used, the rites and ceremonies centering round Motunui and Orongo [7] and the great

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[6] This will shortly be published, through the agency of my Swiss colleague Alfred Métraux, by the Bishop Museum, Honolulu.
[7] An islet and village situated to the west of Easter Island.

god Maké Maké continued to take place. The last bird-man was drawn, according to Thompson, in 1880. It may be recalled that the house of the bird-man, the tomb reserved for him, was inside the *tapu* surrounding the quarry whence came the statues and where the oldest still stand. This is presumptive evidence in favor of a close connection between the cult of Orongo and that of ancestors. Perhaps sufficient importance has not been attached to the fact that Orongo contains breccia sculptures from Rano Raraku,[8] and that it is from Orongo that there came the most perfect example of the typical Easter Island statue, that at the British Museum.

Take on the other hand all those manifestations of the plastic skill of the Pascuans—the sculptures on stone and wood, the designs of the rock-carvings and tablets, of the rock paintings and tattoo marks. The technique varies with the raw material, but the uniformity of style is indisputable.

The abrupt end, as it seems, of the activities of Rano Raraku has been invoked both by the adherents of the theory of an age-old lost civilization and by those who favor the idea of a dual Pascuan culture. But the arrest of activity can be explained by simple, almost contemporary, causes. The exploitation of the volcano was controlled by the clan of the Tupahotus, and, as everywhere in Polynesia, by a group of specialists. It required only a war to partially destroy the specialists—and tradition tells of many wars at the beginning of the nineteenth century. An epidemic imported by the whalers might equally be responsible; today each vessel that arrives brings some malady to the Pascuans. Finally, the Peruvian raids (1859–61) are traditionally reported to have given the coup-de-grace to the class of *maoris* (experts).

The fact that in 1886 the Pascuans had already forgotten how and why their activities had been brought to a close, as well as other facts about their culture—such as how the statues were transported, and the meaning of the tablets—is no evidence of the antiquity of these facts, nor does it justify an attribution to another culture. For we have seen these same Pascuans refusing to admit that the stone adzes could have been used to work wood; while it is certain that before 1860 iron must have been very rare in the island, and that their immediate forebears must necessarily have worked wood with the aforesaid adzes. On the other hand they freely admit that adzes and stone chisels were used to work the two kinds of andesite of which the statues, bols, and house stones were made. By a curious inversion the Pascuan regards wood as being harder and more difficult to work than

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[8] A volcano in the eastern part of Easter Island. On its slopes is the quarry where the statues were hewn.

stone, so easy to fashion is the stone of this island. This argument [9] can be used against those who put forward the alleged difficulty of carving igneous rock as a reason for attributing them to a race more skilled, more strong, and gifted with better implements than the Polynesians.

But to return to the first Polynesian colonists. Very probably the fauna and flora of Easter Island were extremely restricted. But following a custom common in all their migrations, they would have taken with them plants, seeds of the most useful vegetables, rats, and chickens. They colonized the island, and their first settlements were at Anakena on the north coast and at Akahanga on the south. They set about conserving rainwater, for Easter Island has no springs. At the same time they learned how to protect the crops against the continual winds. They were familiar with certain crafts which they hold in common with all Polynesians—the making of cloth from mulberry bark (tapa) and the working of wood and stone. The latter craft differs only from that found in the other Polynesian islands in respect of the size of the monuments. The abundance of easily carved stone was the sole predetermining cause of the Pascuans erecting on their island the largest statues found in the islands of Oceania.

The technical skill of the former inhabitants is seen also in the manufacture of implements and weapons of obsidian, and of fish-hooks of stone and bone. These last were made with human bone, for man was the only mammal available with bones large enough. The Pascuan writing on wood shows their skill and taste. There have been found a large number of rock paintings and engravings, the former magical, the latter merely trial pieces.

The Pascuan house, when it is above ground, shows many technical analogies with the Hawaiian house, which, like it, is roofed with tufts of grass set on a framework of boughs. Whenever possible, the Pascuans settled themselves in artificial caves or holes in the ground, which provided a less precarious shelter in war and against thieves. The fowl house was built on the same principles.

The Pascuans were tatooed, and on feast days they painted their bodies with appropriate emblems.

Ten family groups or clans divided up the island between them. The king belonged to the clan of Miru. His place of residence changed, and his role was indeterminate. Many taboos, notably in the matter of food, isolated him from Pascuan life. He did not engage in the wars which often broke out between the clans of the west and north and those of the east (Kotuu against Hotu Iti). He pre-

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[9] Unfortunately, however, the mystery mongers are not as a rule open to reason. Mystery is their religion.—Translator.

sided over the experts in *rongorongo*, the repository of ancient traditions, genealogies, etc. They used tablets (Kohau *rongorongo*) engraved with signs as an aid to memory. The signs of *rongorongo* were the object of organized teaching.

The Pascuans practiced a form of double inhumation. The body was exposed on the *ahu* until the flesh dried up or turned to dust. The bones were then placed in the burial chambers. Sometimes the skull was preserved separately. There was a general fear of the spirits of the dead. Commemorative feasts were held in front of the tombs, where chickens were exchanged for a ritual purpose. The statues at the foot of Rano Raraku represent the dead. Several of them have tatoo marks which were still used during the historical period. Later, the images of the dead also were placed on the *ahus*.

The Pascuans had a large number of gods, the chief of whom was Maké Maké. The same name appeared in other Polynesian mythologies. It would seem to be connected with the source of that which supplied the material needs of the Pascuans—cultivation and fishing. It was thus connected with the Marquesan Tiki, whose mask it resembled in almost every detail. Maké Maké is the creator of birds. One of the less obscure features of his cult is the indication, by means of birds, of a man [10] who probably represents the god, and who each spring gives place to another. Ritual feasts at which human flesh was eaten were a part of this cult, as well as also initiation ceremonies at puberty.

The end of the old culture was hastened by the arrival of Europeans, who revealed a new world to the Pascuans, a world totally different from their own. From that time onward they lost without any effort both peace and the joy of life. Their restless spirit drove them to undertake the most savage warfare, which decimated them, ruined their culture and overthrew its monuments. Works of art were given up, traditions were lost, so that even the memory of their existence has perished. The whalers and slavers completed the task of destruction already well advanced. After being Christianized the Pascuans became ashamed of most of their past history, and essayed, not without success, to remove all traces of it from memory.

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[10] Tangata Manu—bird man. He was the first to get possession of the first egg laid by the bird *Manutara* (breast) in the island of Motunui (spring equinox).

PLATE 1
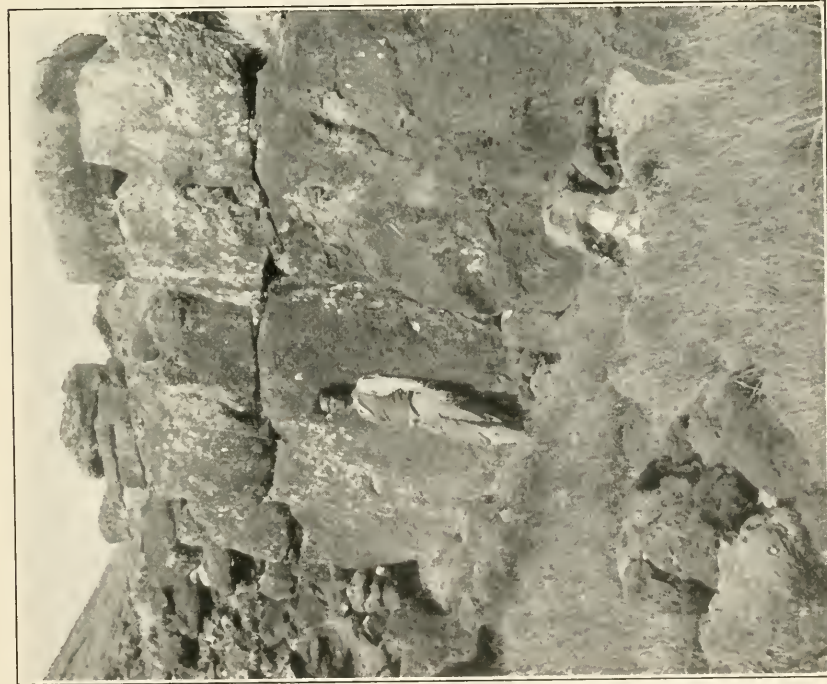
1. FACADE FACING SEA, AHU OF ANAKENA, EASTER ISLAND.

The huge blocks are worked only at the joints.

2. VOLCANO OF RANO RARAKU, EASTER ISLAND, SHOWING STATUES BELOW QUARRY.

PLATE 2
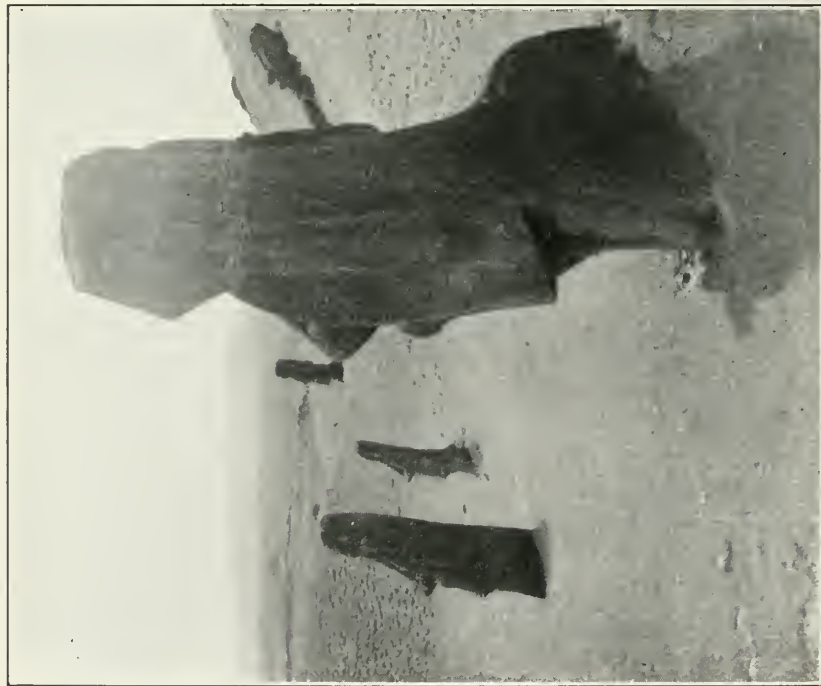
1. STATUES AT THE FOOT OF THE VOLCANO, RANO RARAKU, EASTER ISLAND.

2. STATUE SHOWING TATTOO MARK ON CHEEK, RANO RARAKU, EASTER ISLAND.

STATUE OF PUHAKONONGA, EASTER ISLAND.

Gift of the Chilean Government to Belgium, brought home by the Belgian schoolship *Mercator* in 1935.

1. Fallen Statue on its Way to an Ahu, Rano Raraku, Easter Island.

2. Rock Carvings Representing the Bird-God, Orongo, Easter Island.

THE ESKIMO ARCHEOLOGY OF GREENLAND [1]

By Dr. Therkel Mathiassen

National Museum, Copenhagen

[With 3 plates]

Archeology in the Arctic has a charm of its own. The surroundings are unusual: The scenery is magnificent, with high, snow-clad mountains and deep fiords; the sea is filled with icebergs or drift ice—the sun shines day and night; seals, whales, caribou, bears, sea fowl, and fish are abundant; and the people are the small dark-haired, brown-skinned, broad-faced Eskimos, the kindest and most helpful people in the whole world.

The work is hard, for the ground is frozen a few inches below the surface; the sun must thaw the earth, and the layers must be examined and removed, to expose a new frozen stratum to the rays of the sun. This frozen soil, however, is an advantage for everything is well preserved for centuries, as in an ice cellar.

In my attempt to elucidate the history of the Eskimos and the archeology of Greenland I shall give some account of work with Eskimo excavations, for two summers in the Canadian Arctic (as a member of Knud Rasmussen's Fifth Thule Expedition) and seven in Greenland, a long series of adventurous and interesting years.

If the district chosen for excavation is still inhabited it is an easy matter to obtain information as to likely sites, for one has only to ask the Greenlanders. They know their country; on their hunting trips they travel all over it, and they use their eyes well, noticing everything unusual in the terrain; and they are, of course, well acquainted with the remains of their forefathers. A Greenlander in Angmagssalik, on the east coast, drew for me a very accurate map of the entire district and indicated on that map more than 100 ruined villages. But that is of course exceptional. Usually one must take a Greenland pilot on a motorboat—or woman's boat—and ask him to point out the ruins of the district, and he will do it very well. If the country is uninhabited, the problem is much more difficult. But there are many things which may serve as a guide: Certain posi-

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tions are preferably chosen for habitations—low islands and points—where conditions for building houses are favorable and where there is good hunting. The vegetation often gives hints: The grass is more luxuriant on formerly inhabited spots, where the ground has for ages been fertilized by organic refuse. Not only grass, but also flowers, often of wonderfully bright colors, may cover the old ruins and thus reveal their existence. Green spots on the coast nearly always mean an old house or camping ground; the older the village is, however, the less luxuriant is the vegetation; and the oldest remains have the same poor vegetation as the surroundings and cannot be discovered in this way.

Many places must be visited, to find the one best suited for excavation; in 1934, in Julianehaab district, I visited more than 140 old villages. Most of the places are quite small habitations, with one or two houses; most of them date only from the seventeenth or eighteenth century. What we require for our purpose is a site with houses which have been inhabited throughout a long period; then there will be found a large midden in front of the houses, and such a midden is the best finding place for specimens.

When such a site is found we set up our camp, our party usually being two white people, three or four Greenlanders, and a Greenland girl to do the housekeeping. The village is surveyed, mapped, and photographed; the turf of some of the houses and midden areas is removed to expose the black culture-earth to the sun. Now the excavation goes slowly forward; each day 1 or 2 inches are thawed and can be excavated and removed; the specimens found are dried, prepared, labeled, and packed. The uncovered stone constructions—houses, tent rings, meat caches, graves—are measured, drawn, and photographed. The stone graves often contain rich finds of grave goods.

The conditions for excavations are quite different in north and in south Greenland. In the north the ground is permanently frozen from about 1 foot below the surface, and thawing proceeds very slowly. The excavation takes a very long time; but, on the other hand, things are here usually well preserved. In the south there is no frozen ground in the summer, and even in the winter frost and thaw alternates. Excavation can proceed quickly, as in southern countries; but things are poorly preserved: All wooden and baleen implements have decayed, and often the bone specimens too, so that only a few stone objects are left as a reward for the hard work of the excavator.

Many other troubles have to be faced: in the north large frozen stones and whale bones, and the water from the melting ice; in the south willow and grass roots and often stormy and rainy weather.

In Greenland the mosquitoes are an awful torment in July and August, not only the ordinary big mosquitoes, but in late summer there are millions of small, stinging flies, which get into eyes, ears, nostrils, and mouth; at many places it is impossible on calm days to work without a mosquito net, and that is an awful nuisance. Without mosquitoes the Arctic summer would be nearly a paradise.

We will now mention a few of the places where excavations have been made, and see what results have been obtained.

The key to the archeology of Greenland was the great find from Naujan in Repulse Bay, north of Hudson Bay in the Canadian Arctic. This village was excavated in 1922, on the Fifth Thule Expedition.

At the south end of a small lake, 40 to 60 feet above the sea, 20 ruined houses were located. The situation was such that it suggested the land had risen about 30 feet since these houses were built. The houses were half underground, round, small, about 10 feet in diameter; the walls were built of stones, turf, and big whale skulls; the roof had been supported with whale ribs and jaw bones; the entrance to the house was through a deep, narrow, stone-set passage.

About 3,000 specimens were found at Naujan, mostly from a big, 3-foot thick refuse heap, found in front of three of the houses. In the frozen earth of this midden the specimens had been very well preserved. A few blades of native copper and a bit of meteoric iron was found and most of the objects were of bone—whale bone, antler, walrus, and narwhal ivory—and stone—slate, flint, jade, soapstone. Very prominent amongst the finds was baleen, shaped to all kinds of implements; whaling had evidently played a great part in the economy of the Naujan Eskimos. Among the specimens must be mentioned harpoon heads, mostly of a special form, with open shaft socket; arrow heads of antler with conical tang; balls of bird bolas; sledge shoes of whale bone and baleen; bows of baleen; knives with bone handles and stone blades; drills; adzes; women's knives; lamps (with a row of knobs near the front edge) and cooking pots of soapstone; fragments of pottery vessels; baleen cups and bowls; many ornamental trinkets of ivory, dolls and other toys.

The culture of this Naujan find is quite different from the culture of the recent inhabitants of this region, the Central Eskimos; these people use only snow houses and are rather caribou hunters than seal hunters. When one asks these Eskimos about the old ruins they say that they belonged to the Tunit, a foreign people who left the country and went to the north, when they themselves reached the coast from inland. These Tunit people were small but strong; the men had bearskin trousers and the women very long boots.

This old culture in the Canadian Arctic, represented by the Naujan find, has been called the Thule culture. There is much evidence to show that this culture in a distant past originated in the neighborhood of Bering Strait, in eastern Siberia, or in north Alaska, and spread thence to the East, across the American Arctic, where its ruins are found everywhere, both on the mainland and in the Arctic archipelago.

In the northernmost part of the west Greenland coast, in the Cape York district, is situated the trading post of Thule, Knud Rasmussen's station, erected to supply the small Polar Eskimo tribe with European goods. In 1916, close to this place, was found a very old Eskimo midden containing many antiquities. The culture represented here is the same Thule culture found in the Canadian Arctic; we have the harpoon heads with open socket, the lamp with a wick ledge, and many baleen objects. These finds show that the Thule Eskimos from the American Arctic also reached Greenland and were the first Eskimo inhabitants of this country.

The recent inhabitants of this region, the Polar Eskimos, have many elements in common with the Thule culture; their men have bearskin trousers and their women long boots, as the "Tunit" of the Canadian Eskimos. And the house of the Polar Eskimos, a round stone house, is a descendant of the whalebone house of the Thule culture.

I spent the summer of 1929 on the small island of Inugsuk, together with my young American assistant, Dr. Frederica de Laguna. The island is situated 10 miles north of Upernivik, the northernmost of the Danish colonies on the west coast, separated from Thule by the large, ice-filled, uninhabited Melville Bay. This small, rocky island is situated in the mouth of Upernivik's ice fiord, one of the most prolific ice-producers derived from the inland ice; the sea around Inugsuk was always filled with enormous icebergs of all sizes and shapes, dangerous neighbors, which in overturning often sent heavy flood waves against the shore. On the west side of this small island was situated the remains of a large old Eskimo village; most of it had already been washed away by the subsidence of the land and the action of the sea.

A small strip of lowland, about 300 feet long and 100 feet wide, was covered with a thick layer of old refuse, and had a cliff 3 to 6 feet high raised over the beach. Here bones, baleen, wooden pieces, and implements were scattered. On the top of this midden were three houses, which were inhabited about 1850; but the lower and greater part of the midden was much older. The ground was frozen solid just below the surface, and it took the whole summer to excavate to the bottom; but Inugsuk proved to be the richest finding place for old Eskimo antiquities which I have met in Greenland.

Everything had been well preserved in this enormous frozen midden—bones, bone and baleen implements, heaps of big unworked baleens, wood, pieces of sealskin, feathers, eggshells, dog excrement, human hair; and the whole was saturated with blubber. On calm sunny days this old thawing midden sent forth a most unpleasant odor. It is a common rule in the Arctic that where the smell is worst, the best finds are to be got; and this was the case at Inugsuk.

About 6,000 worked specimens were taken from this midden during the summer, and many of them were of great interest. Most of the implements were of types well known from Naujan, Thule, and the other sites of the Thule culture. Some of the harpoon heads had the same open sockets; we found the same kinds of arrowheads, bola balls, sledge shoes, knife handles, drills, adzes, women's knives, lamps (with wick ledge), cooking pots, baleen bowls, trinkets, and toys. The baleen implements were very prominent—bows, sledge shoes, snow beaters, weapon points, knives, cups, large pieces of platform mats, tops, toys; even a house door, a drying rack, and a drum frame of baleen. The Inugsuk people too had been great whalers.

The Inugsuk culture is not identical with the Thule culture; something new had been added, which gives the find a younger stamp. Most of the harpoon heads have a closed socket; some special west Greenland types have appeared, some implements of silicious slate, some ornamental bodkins, some antler spoons and coopered vessels. And some of these new types seem to be influenced by a foreign culture—the culture of the medieval Norsemen who in the 5 centuries from about 1000 to 1500 existed in south Greenland. These Norsemen were familiar with the coopering technique, and they used spoons of the same shape as those found at Inugsuk. But can these Norsemen really have had any communication with the Inugsuk Eskimos, who lived 500 to 600 miles farther north?

We found, however, at Inugsuk more evidence of this connection— a lump of church-bell metal, used as a hammer; a piece of woven cloth, of the same kind as that found in the Norse churchyards in south Greenland; a bone chessman, converted into a top; and two wooden carvings, made by Eskimos, but representing Norsemen; one of them is a small doll, showing a Norseman in medieval dress, with long coat and big, loose hood, the same dress as that which has been found in the Norse churchyard of Herjolfsnes in south Greenland. The Inugsuk people must actually have seen Norsemen. Now, fortunately, we know that there really were three Norsemen up here in the latter part of the thirteenth century; for on another island, close to Inugsuk, there was found about 100 years ago a runic inscribed stone, saying that "Erling Sigvattsson and Bjarne Tordsson and Enride Oddsson erected this cairn on the Saturday before soccage day." The language enables us to fix the date.

These Norse relics at Inugsuk are very important. Not only are they important for the elucidation of the connection between Norsemen and Eskimos, but they give us a means of dating approximately the Inugsuk culture; it must belong to the thirteenth and fourteenth centuries. The Thule culture then must be some centuries earlier.

We now move into the southernmost part of west Greenland, the Julianehaab district. Here we worked during the summer of 1934, spending about 5 weeks at the village site of Tugtutôq, situated at the north point of a large island. The name means "caribou place"; the caribou has, however, been extinct for 100 years.

It was an extensive village, with ruins of 24 houses. The oldest of them are now only to be distinguished as shallow depressions in the gravel terrace, covered by heather and lichen; others have willow bush and the latest are grass-grown.

The climate here is quite different from that which we experienced at Inugsuk. It is not so cold, but the weather is more unsettled, both in summer and winter; frost and thaw alternate even in the winter, and in summer there is much stormy and rainy weather—and any number of mosquitoes. The excavation was easy—except for floods of melting water in the spring—but the objects were very poorly preserved; most of the houses only contained stone objects, mostly whetting and hammerstones and soapstone pot fragments. The houses, however, were well preserved: the oldest were small, round, and half underground, with a deep sunken doorway, stone walls, poorly built, stone paved floor, and often a kitchen, forming a bulge in the front wall, where there had been cooking with bone and blubber. This house type is no doubt derived from the whalebone house of the Thule culture but stones and driftwood have replaced whalebone.

The specimens found in the 20 excavated houses of this type were not very numerous but they were sufficient to tell us that the Eskimo inhabitants belong to the Inugsuk culture. Very prominent amongst the finds were fragments of soapstone lamps with wick-ledge and objects derived from the Norsemen—pieces of bell metal and of iron, soapstone, spindle whorls (one with a runic inscription), a piece of woven cloth, fragments of soapstone vessels, and net sinkers.

The Julianehaab district in the medieval period was the center of the Norse colonies in Greenland, the "East Settlement." Here the Icelanders settled as sheep and cattle breeders, after Eric the Red had discovered Greenland in 985, and here for 5 centuries there lived a numerous population with 190 farms, several churches, and monasteries. At first the Norse Greenlanders were quite prosperous but from the fourteenth century onward communication with Iceland and Norway became less regular until it ceased entirely at the beginning of the fifteenth century; and when white people again went to

Greenland in the sixteenth century the Norsemen had disappeared, having died out—only the ruins of their houses told that the land had formerly been peopled by a white race. What had happened?

The Norsemen first met the Eskimos about 1200, on hunting trips to the northwest coast; as the Inugsuk find showed, there had been some connection between Norsemen and Eskimos. The Eskimos only inhabited the west coast as far south as the climate was Arctic, with that winter ice which was necessary for their ice hunting and dog sledges. But in the fourteenth century the Eskimos began to move southward. About 1350 they attacked and destroyed the Norse "Western Settlement", and in 1379 we hear about the first attack on the "Eastern Settlement." And now the Norse colonization began quickly to decline.

The Norsemen were then already a degenerate race, as Dr. Poul Nörlund's excavations in the churchyard at Herjolfsnes has shown: they were sick, undernourished, degenerate, and weak. The Norsemen, of course, looked with contempt on the Eskimos, these small, black heathen; and they probably killed them whenever they met. But the Eskimos had a fighting method of their own: they attacked the Norsemen individually and from behind with their very effective weapons, bows and slings; or they burned the Norse houses, after having blocked up the doors. The tales of the Greenlanders relate how the last chief of the Norsemen, Ungortoq, fled out of his burning house with his little son in his arms, and then, when the Eskimos pursued him, threw the boy into a lake so that he should not be taken alive.

The Norse colonies disappeared and the Eskimos plundered the habitations, which explains how they got all those Norse objects which we now find in the old Eskimo ruins. The Norsemen certainly did not break their church bells voluntarily so that the Eskimos might make hammers or eardrops out of the fragments.

Halfway up the fiords we now find the ruins of these, the oldest Eskimos villages; there they could still do some hunting from the ice in the winter, as they were accustomed to from their northern home. But later they scattered all over the country and also onto the outer skerries; their Kayak technique was now sufficiently developed to stand the south Greenland winter.

The later houses at Tugtutôq belong to this period, the seventeenth and eighteenth centuries. The houses are now big, square communal dwellings for several families, each containing 30 to 50 persons. The walls were of stones and turf, the floor paved with flat stones, the platform and roof of driftwood. It was the kind of house still used when the Danish colonization of Greenland began with Hans Egede in 1721, and which is still used in Angmagssalik on the east coast.

These house ruins contain Eskimo implements of more modern type and also glass beads, clay pipes, and iron goods brought to Greenland by the Dutch whalers.

The Eskimo immigrants to the Julianehaab district soon passed on south through the region of Cape Farewell, to the east coast. The oldest house ruins at Angmagssalik are of exactly the same form and contain exactly the same type of implements as the oldest houses at Tugtutôq; already early in the fifteenth century the Eskimos had reached Angmagssalik. They did not, however, stop here but wandered still farther north. The oldest houses in northeast Greenland also contain Inugsuk culture. But soon this culture was intermingled with other elements, brought by some Eskimos who from the Thule district wandered on northward and reached northeast Greenland, where they lived for centuries, but only once did white people see them; Clavering met a small party of them on Clavering Island in 1823. Since then they have all become extinct.

In Angmagssalik there is, however, still a prosperous Eskimo population; since 1894, a Danish trading post has been situated there. A curious and in some respects old-fashioned (but in others, highly-developed) culture was found amongst these Angmagssalikers, when the first white man, Gustav Holm, visited and spent a winter amongst them in 1884. In 1925 a hundred of them were transplanted to the newly founded colony on Scoresby Sound. East Greenland now has a population of about 1,000 Greenlanders, the west coast has about 16,000, and the Thule district 300.

Civilization has now come to the Greenlanders. In South Greenland fishing has more and more displaced seal hunting; the yawl and motorboat have succeeded the kayak and woman's boat; the rubber boot, the kamik shin-boot; the gun, the harpoon; and the wooden house, the old turf hut. The old Eskimo culture in Greenland will soon exist only in the old house-ruins and graves, and in the museums.

This paper is a résumé of the following publications of the author:
1927. Archaeology of the Central Eskimos, I–II. Rep. 5th Thule Exped., vol. 4.
1930. Inugsuk, a medieval Eskimo settlement in Upernivik district, West Greenland. Meddel. Grönland, vol. 77.
1931. Ancient Eskimo settlements in the Kangâmiut area. Idem, vol. 91, no. 1.
1933. Prehistory of the Angmagssalik Eskimos. Idem, vol. 92, no. 4.
1934. Contributions to the Archaeology of Disko Bay. Idem, vol. 93, no. 2.
1936. The former Eskimo settlements on Frederik VI's coast. Idem, vol 109, no. 2.
1936. The Eskimo archaeology of Julianehaab district. Idem, vol. 118, no. 1.

PLATE 1
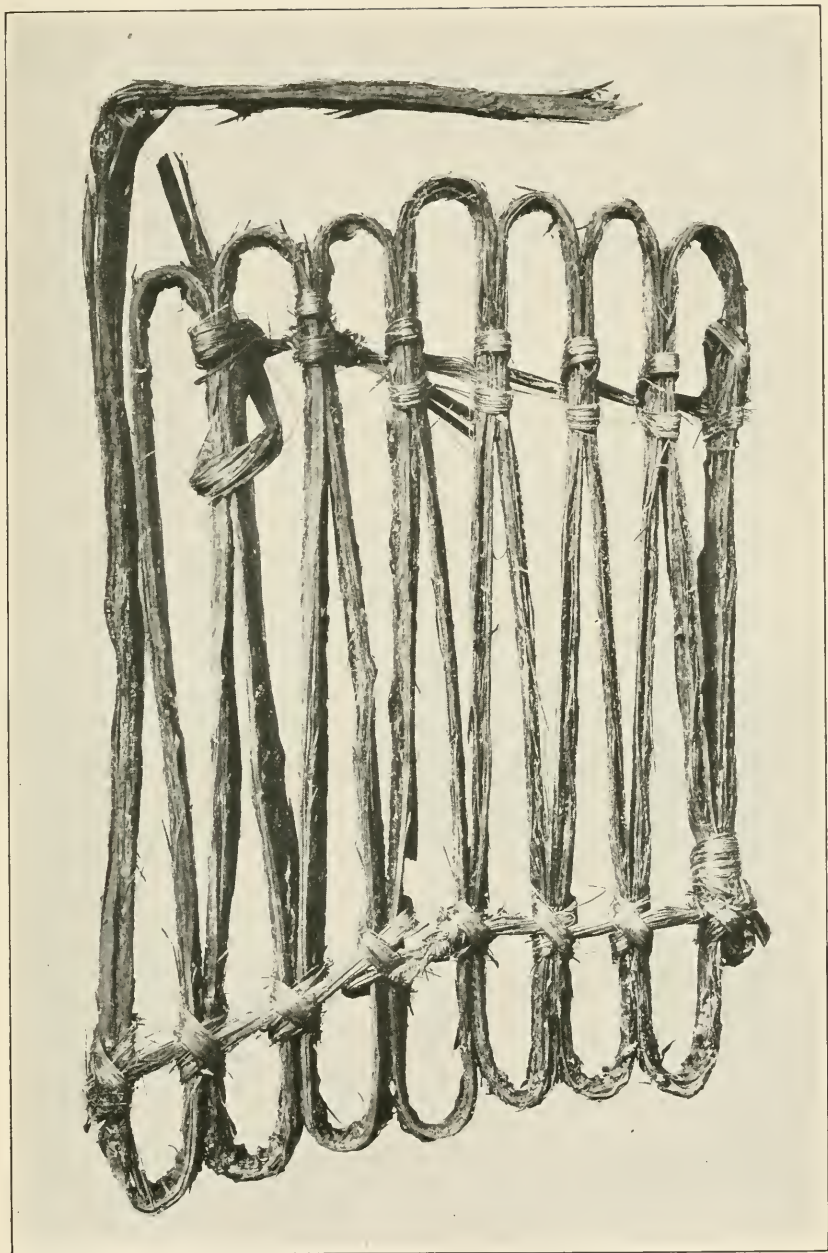
PLATFORM MAT OF BALEEN FROM THE CANADIAN THULE CULTURE.   1:2.

PLATE 2

TYPES OF THE INUGSUK CULTURE.

1-5, Harpoon heads; 6, arrowhead; 7, wound needle; 8, gull hook; 9, bird dart side-prong; 10-16, stone blades for weapons and tools; 17-19, ornamental bodkins; 20-22, pendants of ivory and stone; 23-25, dolls of wood and ivory; 26, comb; 27, amulet box; 28, toy lamp; 29, needle case.   2 : 3.

NORSE INFLUENCE IN THE INUGSUK CULTURE.

1. Lump of church bell metal. 1:1. 2. Coopered tub with baleen hoops. 1:3. 3. Norse doll, carved by Eskimo. 1:1.

4. House of the old round type, seen from the entrance. Julianehaab district.

PETROGLYPHS OF THE UNITED STATES

By Julian H. Steward
Bureau of American Ethnology

[With 12 plates]

More than three centuries ago men began to wrinkle their brows over the origin of the American aborigines. Learned and even bitter discussion, often participated in by the earliest American colonists, sought to connect the Indians and their archeological remains with every race and civilization on the face of the earth. In the course of time, however, when the development of anthropology injected scientific method into the study of the Indian, this riot of fancy began to yield to ordered and sane theories. The question of racial origins was satisfactorily settled by the theory of early migrations of a predominantly mongoloid people from Asia into Alaska and America. The assumption that Old World civilizations were brought to America was supplanted by archeological reconstruction which traced the development of American cultures on native soil.

But there was one class of American antiquities to which the blessings of scientific method came but slowly—the carved and painted petroglyphs [1] which are found on rocks in all parts of the United States. Here amateur speculation retained its hold and, zealous in its last stand, even today stoutly resists the threats of science. Popular fancy musters petroglyphs in support of theories abandoned by science half a century ago. It offers them as proof that Egyptians, Scythians, Chinese, and a host of other Old World peoples, including the Ten Lost Tribes of Israel, whose fate continues to have absorbing interest to many persons, invaded America in ancient days. It claims them to be markers of buried treasure, signs of ancient astrology, records of vanished races, symbols of diabolical cults, works of the hand of God, and a hundred other things conceived by feverish brains. Devotees of the subject have written voluminously, argued bitterly, and even fought duels.

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[1] In an earlier paper, the writer called the carved rock figures petroglyphs, the painted ones pictographs. It seems preferable, however, to designate all designs and figures on rocks petroglyphs (literally, rock glyphs) and to reserve pictograph for that primitive type of writing in which objects and events are represented pictorially on all kinds of materials.

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Owing largely to methodological difficulties in the study of petroglyphs, archeologists have unduly neglected them. It was not until 1886 that petroglyphs were accorded their first comprehensive and genuinely scientific treatment. Garrick Mallery, interested in the primitive pictographic writing used by certain North American Indians, included many petroglyphs in a large volume, Pictographs of the American Indians, published in the Fourth Annual Report of the Bureau of American Ethnology. In a subsequent and more extensive treatment of the same subject, Picture-writing of the American Indians, Tenth Annual Report of the Bureau of American Ethnology, 1893, he published further material on petroglyphs. Although Mallery drew attention to the many similarities between petroglyphs and pictographic writing, he warned against any interpretations of the former which could not meet rigid scientific standards. Unscientific speculation continued rife, however, and is still unabated today.

With the great increase of scientific archeological research during the past few decades, photographs, sketches, and even published works on petroglyphs have rapidly accumulated in scientific institutions. In 1929 the writer used the materials on record at the University of California to make a systematic, comparative study of the petroglyphs of California, Lower California, Nevada, Utah, and Arizona, endeavoring to give them historical sequence and, when possible, rational interpretation (Petroglyphs of California and Adjoining States, University of California, Publications in American Archeology and Ethnology, vol. 24, no. 2, pp. 47–238, 1929). Meanwhile, thanks largely to the enthusiastic cooperation of many nonprofessional observers who have painstakingly sketched and photographed petroglyphs, material has continued to accumulate in scientific institutions. Little has been published, but when competent archeologists can be enticed to set aside their spades long enough to ponder petroglyphs, we may expect a much better understanding of this interesting subject.

Petroglyphs are not unique in America. Carved and painted figures are common on all continents, though only those which have exceptional interest are well known. The graceful, lifelike paintings of wild animals and human beings made by the pygmy Bushmen of South Africa and the remarkably faithful portrayals of mammoths, giant bison, reindeer, and other ice-age animals painted by the paleolithic Cro-Magnon men in Europe represent the height of primitive art and have received well-deserved publicity. But there are on all continents many simpler and cruder drawings, made by usually unknown artists, which have been accorded little attention.

American petroglyphs are extraordinarily varied. Some are so

complex in design and so striking in pictography that they readily
excite interest. Others represent art and symbolism at its lowliest.
Paradoxically, the most interesting are least known. Even in Colo-
nial times, certain eastern petroglyphs commanded attention and
they have monopolized it until recently. Nevertheless, petroglyphs
are far more numerous west of the Rocky Mountains, where the large
number of smooth rock faces provided by caves, cliffs, and boulders
afforded opportunities for this art and where the semiarid climate has
preserved them from destruction by the elements. There is scarcely
a mountainside, canyon, or other place frequented by primitive man
where some trace of them may not be found.

SOME COMMON MISTAKES ABOUT PETROGLYPHS

It is the unhappy lot of science that it must clear the ground of
flimsy and fanciful structures built upon false premises and errors
of fact before it can build anew. Probably nothing in the entire
field of archeology has produced greater excesses of misinformation
than the significance and authorship of petroglyphs. Unintelligible,
mysterious, and supposedly occult, they have stimulated a veritable
orgy of mad speculation. Surely their primitive makers would have
hesitated had they been able to foresee the furor their efforts were to
cause. Let us review some of the more common misconceptions and
appraise them in the light of archeology.

Some persons, who cling to hypotheses that were abandoned when
archeology became a science, are determined to prove that Egyptians,
Babylonians, Hebrews, Greeks, Romans, Chinese and other Old
World peoples reached America long ago. They interpret petro-
glyphs as records of trans-Pacific migrations and of strange deeds
of antiquity. Others, undaunted by the facts of scientific archeology
and geology, spend incredible energy trying to relate petroglyphs to
the cultures of those imaginary oceanic cradles of civilization, the
"lost continents" of Atlantis and Mu. Some, more loyal to native
soil, have thought that petroglyphs proved that the Garden of Eden
lay in America. An amateur expedition, with more enthusiasm and
money than scientific training and caution, once spent thousands of
dollars in an attempt to show that the rock designs in western Ne-
vada were proof that all systems of writing and all civilizations of
the world were conceived in these sage-covered valleys. More moder-
ate imaginations are content to regard petroglyphs as evidence of
Aztec wanderings.

All of these interpretations are similar in that, reluctant to enter-
tain commonplace and common-sense explanations, they first con-
coct a story of mystery and glamor and subsequently seek facts to
support it. They illustrate a priori, deductive thinking at its worst.

None, however, can be reconciled with scientifically acceptable theories of human prehistory.

Anthropologists are generally agreed that America was peopled from Asia by mongoloid immigrants who wandered across Bering Strait to Alaska before the invention of writing. There is no evidence whatever that Egyptians, Hebrews, or any other advanced peoples sailed across the Pacific or Atlantic Oceans bringing civilization to America. The supposition that the first civilization sprang up on now sunken continents in either ocean does not accord with geology and is totally unsupported by any archeological evidence. The notion that America was the cradle of all world civilizations is equally untenable, for the facts of archeology show that Old and New World civilization developed in complete independence of one another. Had any Old World peoples visited America in sufficient numbers to make all the petroglyphs assigned to them by various writers, they could not have failed to leave abundant evidence of their presence in the form of such other types of archeological remains as houses, tools, weapons, etc. But nothing of the sort has ever been found.

Even the theory of far-flung Aztec migrations must be barred from serious consideration, for petroglyphs of the United States have nothing in common with either the art or writing of Middle America; nor is there any other archeological evidence to show that the Aztecs ever went north of the Valley of Mexico. The rare occurrence of a particular figure, such as the plumed serpent, in both Middle America and North America, is explainable as the diffusion of an idea, like the spread of modern styles in clothing in the civilized world.

An extremely popular explanation of petroglyphs, entertained largely by overoptimistic minds, is the legend of buried treasures, in name of which an unbelievable number of archeological sites have been looted and precious records of early man destroyed forever. These legends are most common in the southeastern and southwestern parts of the United States, where, it is supposed, early Spanish treasures were buried and marked by petroglyphs. The accuracy of these tales is shown by the fact that the same elaborate fable will be told in identical form of a dozen different localities. Whether, however, the hope be that petroglyphs mark buried wealth or are treasure maps, the quests have always been fruitless despite untold hours of laborious digging. And they will always be futile, for extensive archeological and ethnological researches have shown that the Indians north of Mexico knew of no stones more precious than turquoise nor metals more precious than copper.

It is commonly supposed that petroglyphs are some kind of long-lost art of writing, the meaning of which will be known when the

American Rosetta stone is found. If writing is understood to be the use of alphabetic symbols, petroglyphs were a far cry from writing; in fact, no alphabet was known to any pre-Columbian American Indians. Even the civilized Maya and Aztec of Middle America had no true letters but wrote instead with symbols representing syllables, a rebus writing; and their system of writing did not spread beyond their immediate neighbors. That an occasional design among the vast variety of shapes and forms in petroglyphs should fortuitously resemble a letter in one of the many alphabets in the world does not, of course, prove the presence of that alphabet. Petroglyphs are so variable and generally so crude in form that it is all too easy for a person bent on proving a thesis to read into them whatever he desires and to find any shapes he seeks.

The North American tribes came no nearer to writing than to employ crude pictures of objects and events, with occasional symbols or ideograms standing for somewhat abstract ideas. (Mallery has treated this subject at great length in Picture Writing of the North American Indians.) Thus, the Indians of the Great Plains drew war counts or realistic pictures of exploits of battle. The pictures are intelligible, however, only to the persons who made them; there is no assurance that even members of the same tribe can understand their import. Moreover, all North American tribes did not write pictographically; it is characteristic principally of those dwelling in the Great Plains and Great Lakes regions. The Great Basin and California tribes knew nothing of such writing. It is not therefore a foregone conclusion that all petroglyphs are pictographic writing; and, as a matter of fact, many definitely were not. And even though some petroglyphs are pictographic (see, for example, pl. 1, A), the artists died so long ago that it is impossible ever to know precisely what they had in mind. A few petroglyphs obviously represent hunting scenes (pl. 9, B), some show dances (fig. 7), but the import of hundreds which clearly depict men and beasts cannot be ascertained, for to the extent that they are writing they are individualistic and do not follow any standard. When, therefore, anyone not excepting Indians, pretends to interpret these, unless he has the direct testimony of the original artist, one may be assured that it is merely his own entirely unfounded guess.

Many persons claim to find characters of Chinese writing among petroglyphs, pointing out that much of Chinese writing is pictographic. Pictographic writing, however, does not conform to universal conventions. Although it has been used in various parts of the world, each system employs its own styles. A fortuitous resemblance of occasional petroglyph designs to Chinese symbols is no proof that the petroglyph *is* Chinese, or, indeed that it is even pictographic writing.

The most that can be affirmed is that in any pictographic system, the character for a man, for example, resembles a man, which is not remarkable. It is profitless, therefore, even to compare petroglyphs to Chinese writing.

Occasional attempts are made to show that Europeans, reaching America in pre-Columbian times, inscribed rocks with Runic, Greek, Latin, or other writing. The striking feature of these claims is that each of several persons will authoritatively announce that the petroglyph represents a different language and that he has translated it with success. A controversy that began 300 years ago has raged about the famous Dighton Rock (pl. 1, B) of Narragansett Bay, Mass., inspiring nearly 600 articles and books. Dighton Rock has been used to prove everything from the presence of buried pirate treasure to the European origin of the American Indian and has been "successfully translated" by various scholars as Scandinavian, Scythian, Hebrew, Phoenician, Egyptian, Persian, Lybian, Trojan, Chinese, and Japanese. Some persons have even claimed that it was not made by man but by God. This orgy of speculation has been summarized by Edmund Burke Delabarre in a sizeable volume, Dighton Rock, 1928. Delabarre very sanely concludes that the petroglyphs on this and other disputed rocks in New England were largely purposeless drawings made by Indians after the arrival of the white man. Some of the post-Columbian names and dates he claims to have found on the rock are, however, not entirely convincing.

As Dighton Rock is not nearly so intricate, baffling or fascinating as hundreds of petroglyphs in the far west, one shudders to think of the riot of speculation, dispute, and scholarly invective had the devotees of Dighton Rock known of them.

It is within the bounds of possibility that some pre-Columbian Norsemen wandered inland from the Atlantic coast and left records of their journeys as petroglyphs. As yet, however, no petroglyph has been satisfactorily proved to have had this origin. The pre-Columbian wanderings in America of other European peoples is totally unsupported by history, archeology, and petroglyphs. Subsequent to 1492, however, white men inscribed rocks in all parts of the country. The famous Inscription Rock, now a national monument, in New Mexico, is a huge register of early explorers beginning with the Spaniards. They placed their names over earlier Indian petroglyphs.

In addition to many moot petroglyphs, there are some which are plain frauds. Although it is not always possible to detect their specious origin, most of them exhibit some patent artificiality. Even these have been the subject of controversy. The fraudulent Grave Creek tablet, claimed to have been found in a mound near the Ohio

River, was the subject of a bitter dispute which concerned not its authenticity but its proper translation and which culminated in scurrilous personal remarks and the challenge to a duel.

Finally, there are many peculiar designs on rocks which are not petroglyphs at all but simply discoloration produced by variations within the rock, differential weathering, or lichens. Although careful scrutiny will quickly reveal the natural source of these markings, they are often convincingly artificial to the untrained eye.

It should be remarked at this point that the mere recording of entirely genuine petroglyphs is usually fraught with possibilities of errors. A good photograph of the untouched inscriptions is best. Often, however, when it is impossible to procure a clear photograph, it is necessary to chalk in the lines if the design is carved. This introduces a real possibility that the person will chalk so as to idealize or that he will see what is actually not there. The greatest danger is in copying, in which one tends unconsciously to record what he thinks the petroglyph is intended to be, not what it really is. Distortions in hand drawings are particularly patent in the many reproductions of Dighton Rock, each person slightly falsifying the real inscriptions to fit his preconceived idea of what they represent.

SOME EXPLANATIONS OF PETROGLYPHS

It is no doubt entirely clear by now that petroglyphs are not in a class by themselves, having some uniquely mysterious significance. Obviously, it would be absurd to suppose that of all possible mediums for the execution of artistic and ideational concepts, the mere recording on rock invests them with special meaning. Pictures, symbols, and designs drawn on stone have no less variety of meaning, purpose, and style than those drawn on wood, skin, bone, or other materials. Modern advertising, for example, has the same intent whether on magazine pages, billboards, or roadside stones. It is futile to seek a single explanation of petroglyphs, for this art differed widely in purpose and style in each period and area.

Learned opinion has tended to divide into opposing schools of interpretation—the idle markings school, which bravely holds that petroglyphs are mere random fancies created in leisurely moments, and the serious purpose school which weightily proclaims that all petroglyphs have deep historical or symbolical meaning.

In favor of the first theory is the undisputed fact that since the coming of the white man, Indians have made hundreds of petroglyphs of men, horses, railroad trains, houses, boats, and other things of civilization (pl. 1, A). And, in view of the great trouble which white men frequently take to deface rocks and trees with names and initials, especially where other persons have done so before them, it

would be foolish to suppose that the motives of prehistoric Indians were not sometimes equally trivial. It is a safe guess that a large number of petroglyphs were produced by persons amusing themselves during dull hours.

Many pre-Columbian petroglyphs, however, must have been made for some definite and important reason, else the designs of each area should not conform in such large degree to a prevailing style and they would not have been worth the immense labor often required to make them. Adherents of the "serious purpose" school, however, frequently err in reading a fictitious unity into all the glyphs on a single stone. Serious or not, there is little question that a great many, if not most, of the complex petroglyphs are composite in origin, consisting of elements added from time to time by persons who were probably inspired by the original design (pl. 9, A). Irregular arrangement and superimposition of figures prove this. Probably very few are the expression of a single vast concept.

The testimony of modern Indians concerning petroglyphs is extraordinarily disappointing. They know of them as landmarks and sometimes believe them to have had a supernatural origin. But even where there is good evidence that the glyphs were made by the tribes now inhabiting the area, the practice seems generally to have been abandoned at the advent of the white man and most knowledge of them promptly lost. The explanation of this is undoubtedly that they were generally of interest only to the persons who made them and the knowledge died with these persons. There is, however, seldom assurance that petroglyphs were made by members of the cultural or linguistic groups now in the area. Nevertheless, a thorough knowledge of modern Indians gives many clues to petroglyphs and sometimes accurate interpretation.

Many though by no mean all petroglyphs were made for religious purposes. Primitive peoples believe the world to be filled with supernatural forces which must be supplicated, placated, or taken into account in some other way at every turn. These forces and spirits are often made more objective through pictures and symbols. A god may be more successfully supplicated if his likeness is present. A supernatural guardian spirit, which has appeared in a dream to some person to offer its aid, will seem more real if one has a tangible symbol of its presence. Ceremonies and rites are more satisfying if there is visible evidence of the supernatural forces with which it is concerned. People, therefore, make wooden and clay images, altars, altar paraphernalia, sacred dress, insignia, and regalia, and, not infrequently, pictorial and symbolical representations on stone.

There is, however, no general explanation of religious art and symbolism. Among ancient Indians as among modern Indians, each

area and tribe had its distinctive complex of beliefs and objective representations of these beliefs. Even a particular form often conveyed very different meaning to different tribes. Thus, a triangle stood for an arrowpoint, mountain, house, or a dozen other things depending upon local fancy and tradition. This is why mere similarity of petroglyphs to known symbols does not necessarily reveal their meaning.

In a few fortunate instances the religious meaning of petroglyphs is remembered by modern tribes. Some of these were made in connection with puberty rites which were important ceremonies to most North American tribes, for through them youths were inducted to the status of adulthood. Among the Quinault Indians of Washington the young boys painted mythical water monsters seen during their puberty visions. Somewhat similarly, girls among the Nez Perce Indians of Idaho painted objects seen in dreams or otherwise involved in their ceremonies. In southern California Luiseño and Cupeño girls underwent an elaborate puberty ritual, after which they raced to a certain rock where each received red iron oxide paint from her parents and painted a zigzag or chain of diamonds symbolizing the rattlesnake (pl. 2, A).

Another semireligious purpose is that of many petroglyphs in the Southwest. Around the cliffs and mesas of the Hopi Indian villages in Arizona there are many familiar designs, such as rain-cloud symbols, clan marks, and others made in the distinctive Hopi art style. In the Great Lakes region there are occasional bird and animal designs, which were probably clan totems, and other realistic and conventionalized figures which may have been pictographic records of religious beliefs, similar to those made on birch bark. Throughout the Colorado River drainage of Utah, there are hundreds of extraordinarily elaborate anthropomorphic figures, made perhaps 1,000 years ago, which seemingly portray either masked dancers or deities (pls. 3, 4, 5). It is also possible that some of the animal pictures and hunting scenes found in various places were part of magic for increasing the species which were important for food or for hunting luck, though not a shred of evidence can be offered in any particular instance to prove it.

Many other petroglyphs, though serious in intent, were nonreligious. There are, for example, many geometric designs in the Southwest which are clearly taken from textile or pottery decoration (pl. 6, fig. 1). It is certain that the highly developed pictographic writing of the Great Plains was frequently executed on rocks, though it may be questioned that many of them are pre-Caucasian. Some petroglyphs seem to have been trail markers or records of visits. A large stone west of the Hopi villages is covered with clan symbols

said to have been made by men journeying to the Grand Canyon. (See Mary Russell F. and Harold S. Colton, Petroglyphs, the Record of a Great Adventure, in the American Anthropologist, new series, vol. 33, no. 1, pp. 32–37, 1931.)

The possible meaning of other petroglyphs will be discussed below under "Types of Petroglyphs."

PETROGLYPHS AS ART

In some localities, petroglyphs provide the only known examples of primitive art. In evaluating their merits, however, several facts must be borne in mind. First, native Indian art north of Mexico had not, with the exception of certain areas of high textile and pottery attainments, achieved either accuracy of form or perfection of execution. Second, rocks offer a resistant medium for carving and usually uneven surfaces for painting. Anyone who has attempted to hammer or scratch a design into granite or basalt with a small rock held in his hand must marvel at the persistence of the ancient artists. Third, it is probable that in most petroglyphs, esthetic motives were secondary to some other purpose. Many of the geometric designs, for example, were certainly not intended to be objects of artistic enjoyment. Some were even placed in dark recesses of caves, as if deliberately concealed from profane scrutiny. Often, where space was limited, figures were ruthlessly drawn over older ones, producing an effect of utter confusion.

It is noteworthy that practically all of the recognizable pictures are of men, mammals, reptiles, birds, and insects. There are very few fish, virtually no plants. Undoubtedly many pictures portray dwellings and objects of general use, but, excepting certain comparatively recent petroglyphs, they are either too crude or too greatly conventionalized to be identifiable.

The artistic merits of the realistic and semirealistic pictures are extremely variable. Human or anthropomorphic beings, for example, vary from the extremely complex, somewhat conventionalized, and carefully executed masked men or god images of eastern Utah (pls. 3 and 4) to crude linear figures produced with a faltering hand and no real effort at realism in the Great Basin and elsewhere (fig. 1). The latter have neither breadth nor depth, and some had degenerated into mere crosses or crosses surmounted by circles.

The finest single example of petroglyph art is an elaborate and very elegant group of human beings near Vernal, in northeastern Utah, placed high on a sandstone cliff. The background is carved away so that the lines of the drawing stand out as a kind of bas-relief (pl. 3).

Other highly stylized local types of petroglyphs are discussed below.

Animals, too, are extremely variable in realism and accuracy (figs. 2 and 3). Although none have the easy grace and faithful portrayal achieved in the Bushman and Cro-Magnon paintings, some are fair likenesses of different species. Others are so crude or so greatly conventionalized that it is possible only to know that they are quadrupeds; lizards cannot be distinguished from mountain lions, rabbits from bear. Quadrupeds are, in fact, generally identifiable only when they possess some salient and unmistakable characteristic, such as the long, curved horns of the mountain sheep, the branching antlers of the deer or elk, or the large head and short horns of the
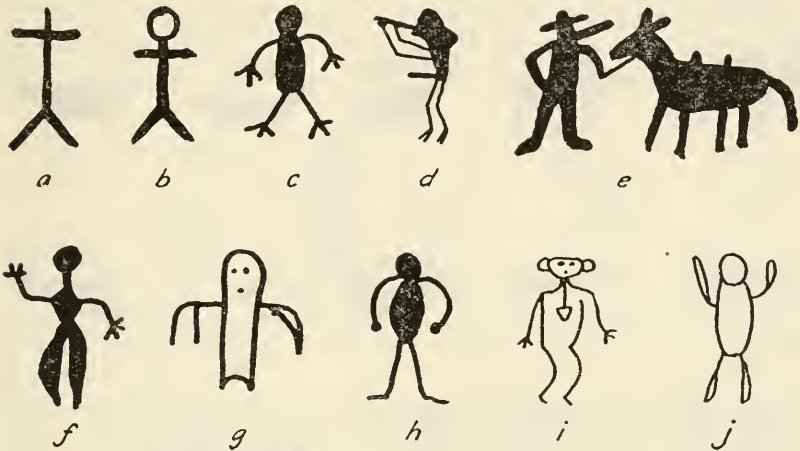
FIGURE 1.—Petroglyphs of human beings. *a*, from near Keeler, eastern Calif.; *b*, from near Yerington, Nev.; *c*, from the lower Gila River, southern Ariz.; *d*, the "hunch back flute player" from near a Pueblo cliff dwelling, Kayenta, northern Ariz.; *e*, man and horse from southern Nev., probably made by modern Southern Paiute Indians; *f*, in Va.; *g*, birdlike being from Pa.; *h*, from Little Indian Rock, Pa.; *i*, at Pipestone, Minn.; *j*, Wyo. All are carved or "pecked".

bison. Often, a distinctive part of an animal suffices for the whole. An antler may indicate a deer; a track may stand for a bear.

In some areas unreal and probably mythical creatures, whose likeness is unknown in the world of nature, defy identification. The amoebalike sketches and many-legged creatures of the southern San Joaquin Valley of California, the club-handed and other grotesque men of the Great Basin, certain ghostlike figures from the Columbia Valley, many composite creatures from all areas, and others probably represent imaginary beings, the identity of which it is futile to guess (fig. 4). Perhaps some complex groups, having several of these fantastic figures, are myth stories; others, as suggested by the Western Mono Indians of California, may be doctor's marks; still others are undoubtedly creatures seen in visions. But it is rare that a particular figure can be identified with certainty.

Ordinarily, geometric designs seem to have no esthetic motivation. Certainly the intricate and wholly unintelligible petroglyphs, consisting of wavy lines, circles, concentric circles, spirals, and miscellaneous crude zoomorphic and anthropomorphic figures found in the Great Basin were not intended as creations of beauty (pl. 7). There

FIGURE 2.—Petroglyphs representing animals. *a* to *e*, mountain sheep: *a*, near Donner Lake, eastern Calif.; *b*, at Little Lake, eastern Calif.; *c*, near Tucson, Ariz.; *d*, Grapevine Canyon, Nev.; *e*, near Kayenta, northern Ariz.; *f*, bison on the Colorado River at the mouth of the Freemont River, Utah; *g*, antelope or mountain goat with young (?), near Kayenta, north Ariz.; *h*, deer or elk, on northern shore of Great Salt Lake; *i*, deer or elk on Colorado River, near the mouth of the Freemont River, Utah; *j*, antelope (?) near the San Francisco mountains, northern Ariz.; *k*, wolf, coyote, or mountain lion (?) on the Gila River, southern Ariz.; *l*, fox (?), on the Gila River; *m*, dog (?), near Fruita, central Utah; *n*, unidentifiable quadruped at Aztec Canyon, Ariz.; *o*, unidentifiable horned animal, possibly a recent petroglyph representing a cow, from near Tucson, Ariz.; *p*, bear, in Nebr.; *q*, bison in Nebr.; *r*, deer or elk or moose, Pipestone, Minn.; *s*, deer, elk, or moose in Maine.

is, however, an artistic value to many of the elaborate polychrome geometric designs of southwestern California, whether their creators intended it or not.

ANTIQUITY OF PETROGLYPHS

Although there is no question that petroglyphs have been made in many different times in the past, it is usually extremely difficult to

ascertain their age. Other types of archeological remains often lie in the ground and, if a site has been occupied by different people or in different periods over many years, the relative age of objects may be determined by removing successive strata. This important technique for the historical reconstruction of cultures cannot be used for petroglyphs because they are not stratified. Even the occasional superimposition of one style over another on the same rock has so far yielded few data on relative age.

There are several means, however, by which the general age may occasionally be ascertained. Geology has sometimes provided important clues. For example, at the Salton Sea, southern California, a few simple, linear petroglyphs occur under layers of travertine, a deposit left on the ancient shore line by the waves of the sea, which was much higher than it is today and filled much of the Imperial
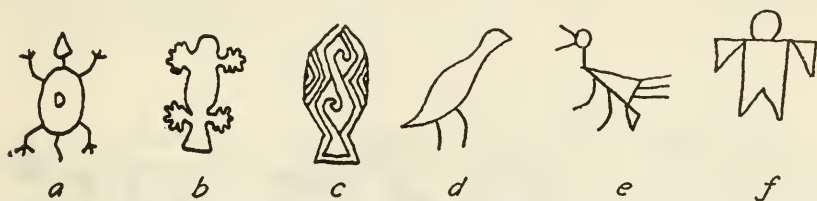
FIGURE 3.—Crudely carved pictures of animals. *a,* turtle ? at Pipestone, Minn.; *b,* beaver in Tulare County, Calif.; *c,* fish, N. Mex.; *d,* bird, W. Va.; *e,* bird, Ariz.; *f,* bird, N. Mex.

Valley. These petroglyphs must, therefore, be as old as this inundation, which geologists believe to have occurred between 300 and 1,000 years ago. Other petroglyphs on the travertine must, on the other hand, be more recent than the inundation.

Near Grapevine Canyon, Nevada, there are many complex rectilinear figures on rock surfaces, part of which are now covered by a gravel terrace. The gravel is a stream deposit which, geologists state, was built up several hundred years ago, possibly longer.

When geologic aspects of this problem have been further exploited, we may expect additional light on the problem of antiquity. Unfortunately, however, geologic estimates of age are always broad and can seldom fix dates with the precision required to relate petroglyphs to other types of archeological remains having known antiquity.

The degree to which petroglyphs have faded out through weathering has been examined with considerable care. This is one of the least reliable measures of age, for the mere appearance of antiquity is no proof whatever of great age. The writer has seen dates carved on rocks not over 10 years ago which have weathered almost beyond recognition, whereas definitely pre-Columbian petroglyphs close by are still bright and fresh. The time required for weather to obliterate a petroglyph depends upon the kind of rock on which it is

placed, the depth of the cut of the figures or the kind of pigment used, and the exposure to sun, rain, and blown sand. Painted petroglyphs in caves of Europe have lasted nearly 25,000 years; in exposed places in America, some have practically disappeared within 50 years. Although degree of weathering may sometimes provide a clue as to age, it is never conclusive.

In some areas it is possible provisionally to relate petroglyphs to known cultural horizons by comparing the subjects and art styles
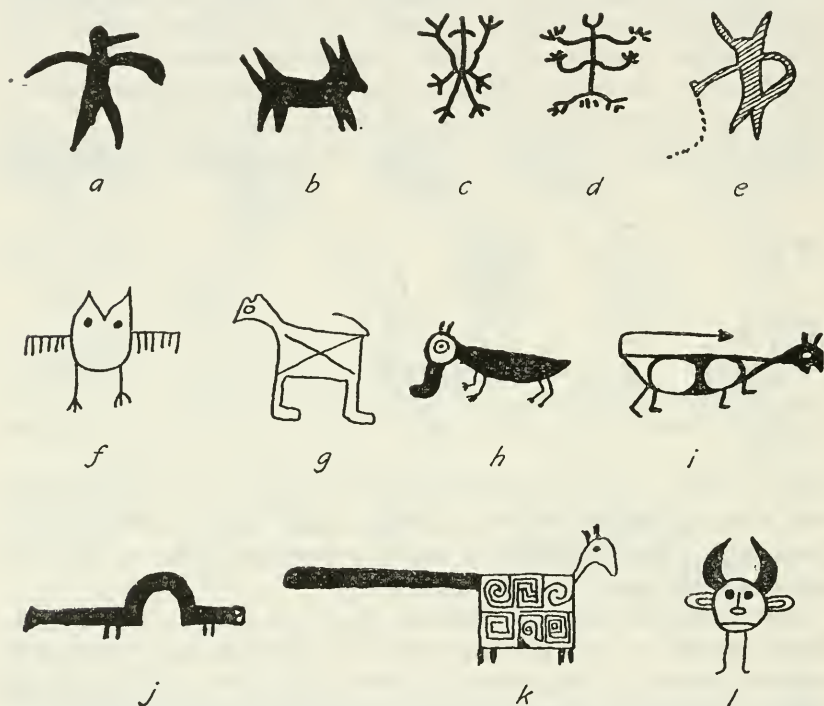
FIGURE 4.—Petroglyphs representing mythical or imaginary beings. *a*, Little Indian Rock, Pa.; *b*, Safe Harbor, Pa.; *c*, Clear Creek, Utah; *d*, near Blairsden, Calif.; *e*, figure in Tulare County, Calif.; *f*, The Dalles, Columbia River; *g* to *l*, N. Mex. *e* is painted red; the others are carved.

of the former with those of objects dug from the ground. Thus when rock designs closely resemble those on a certain type of pottery (e. g., pl. 6), it is reasonably certain that the two were made by the same people. Evidence of this kind is more fully discussed below. There are, however, many dangers of misinterpreting these similarities. This method, though one of the most promising, must be carried out in much greater detail before its results will be satisfactory.

Now and then it is claimed that some petroglyph represents a now extinct species of animal. When it is asserted, as in Arizona

a few years ago, that the pictures are dinosaurs, it is sheer nonsense, for the great reptiles were extinct long before man had begun to evolve anywhere on the face of the earth. When, however, the petroglyphs are thought to be of the giant bison, mammoth, ground sloth, camel, or others of the great Pleistocene mammals which are now known to have survived after man's advent to the New World, the claim should be examined with care, for it is entirely possible that human beings did depict these now extinct species (pl. 8). So far, however, none of these claims is wholly convincing, for careless and unskilled drawing produced such distortions of the humbler species that they might easily be mistaken for anything under the sun and for many things that never existed. It is very often impossible to know whether the artist intended a now extinct species, or a purely imaginary creature or whether he simply could not draw any better. As well suppose that the blundering scrawls of modern children are prehistoric monsters.

TYPES OF PETROGLYPHS

As all American petroglyphs cannot be subsumed under a single description or explanation, we will now review some of the more important types. Each area tends to have a distinctive style, which includes both special geometric forms and conventions in handling realistic subjects.

Probably the greatest number of petroglyphs occur in the Great Basin, that high, sage-covered region between the Wasatch Mountains on the east, the Sierra Nevada Mountains on the west, the Columbia Plateau on the north, and the Colorado Plateau on the south. The large number of extremely hard granitic and basaltic rocks were favored mediums and the semiarid climate has preserved the petroglyphs extraordinarily well. If there were formerly also painted pictures or if the carved designs bore paint, time has removed nearly all traces of them. The complete failure of the modern Shoshonean tribes of this region to understand the source of them, and the geologic evidence from such sites as Grapevine Canyon and the Salton Sea, mentioned above, as well as the frequent covering of the figures with desert varnish, a peculiar oxidation that slowly coats certain desert rocks, all point to considerable antiquity of most, though not necessarily all, of these petroglyphs.

It is as impossible to interpret as to assign authorship to these petroglyphs. Although no two are alike, all have a similarity which indicates a definite purpose. Characteristically, they are geometric, comprising bewildering combinations of rambling, wavy, or zigzag lines, which connect circles and are interspersed with concentric, spoked, and bisected circles, "sun disks", spirals, crosses, dots,

crossed lines, and rectilinear "gridiron" figures and others which look like elaborate house plans (fig. 5; pl. 7). They also include many inexpertly drawn naturalistic figures, such as human beings, mountain sheep, deer, snakes, lizards, birds and bird tracks, and representations of human hands and human or bear tracks.

Considerable speculation about the meaning of these figures has never produced more than sheer guesses. The commonest supposition is that the complex geometric designs are maps. Even though it cannot be positively stated that maps were never made, this is not

FIGURE 5.—Petroglyph near Meadow Lake, northeastern Calif., illustrating the old Great Basin style of curvilinear designs.

the general explanation of these petroglyphs. Not only have all those studied by the author failed to correspond in the slightest degree with the surrounding country, but it is difficult to see why primitive tribes should have wished to make maps. The modern Shoshonean tribes inhabiting this area not only knew nothing of maps, but had no need for them. Each hunting band habitually moved in territory which it knew intimately and would certainly not have wished to aid strangers to find their way around.

It has also been guessed that some of these are pictographic histories and that others were for hunting magic. Such guesses are beyond the possibility of proof, pro or con.

A popular local theory to account for certain petroglyphs representing human footprints (see pl. 7) is that they were made by early

Indians fleeing barefoot over the then molten lava! How this explanation is thought also to account for footprints in sandstone, which run up the sides and across the ceilings of caves is not clear. The fact is that all such footprints were pecked into the stone by means of a small stone held in the hand.

One of the most interesting styles of painted petroglyphs seems to have originated with the Basket Makers, the first farmers of the Southwest who left various of their remains in sandstone caves of northern Arizona, New Mexico, southern Utah, and Colorado during the last few centuries before Christ. These are simple anthropomorphic figures with triangular bodies and squarish heads, usually in red, and generally occurring on the walls of caves known to have been inhabited by the Basket Makers (pl. 4, A).

Sometime during the following centuries, perhaps in the first millenium after Christ, a people living on the Colorado Plateau in eastern Utah borrowed this simple Basket Maker art and developed it with extraordinary success. The modest figures were enlarged and elaborated to become the finest petroglyphs north of Mexico. It is possible that intensive study some day will reveal periods of growth and interesting local variations. At present we can only know that they all belong to the same general culture, a culture which had its roots in the Basket Maker customs but was influenced by the subsequent Pueblo peoples.

These striking figures are sometimes carved, sometimes painted, sometimes both (pls. 3, 4, 5). Often whole canyon walls are covered with imposing galleries of regal and unearthly beings which may be gods or may be men. When painted, they are often in three and four colors; when carved and incised, they are executed with a care and precision unequaled elsewhere. The square-shouldered bodies are surmounted by squarish heads which may well depict masks (but no masks have ever been found in pre-Columbian Southwestern archeological sites) and which are surmounted by antlers of different kinds, "feathers", and other ornaments which were undoubtedly identifying symbols. The faces usually have eyes, a refinement rare among petroglyphs elsewhere, and below the eyes are two thin lines, which strangely resemble but are certainly not connected with the "tear marks" on faces in Tiahuanacoid drawings in ancient Peru. Earrings and necklaces are shown in great profusion and often the body bears elaborate designs. Certain round-bodied figures look much as if they were men standing behind great shields (fig. 6).

Some of these manlike petroglyphs carry in one hand what appears to be a head (pl. 5, A and B). The supposition that they are headhunters may be correct, though it is completely without proof. Another explanation is that the "heads" are in reality masks.

It is tempting to speculate about the significance of these drawings, and some very incautious interpretations have been made. That the figures resemble certain clay figurines found in puebloan sites in western Utah, that they are made with remarkable care, that they are reminiscent of the Kachinas or masked god-impersonators of the modern Pueblo Indians, and that some sort of symbolism seems to occur in the headgear strongly suggest a religious purpose. But
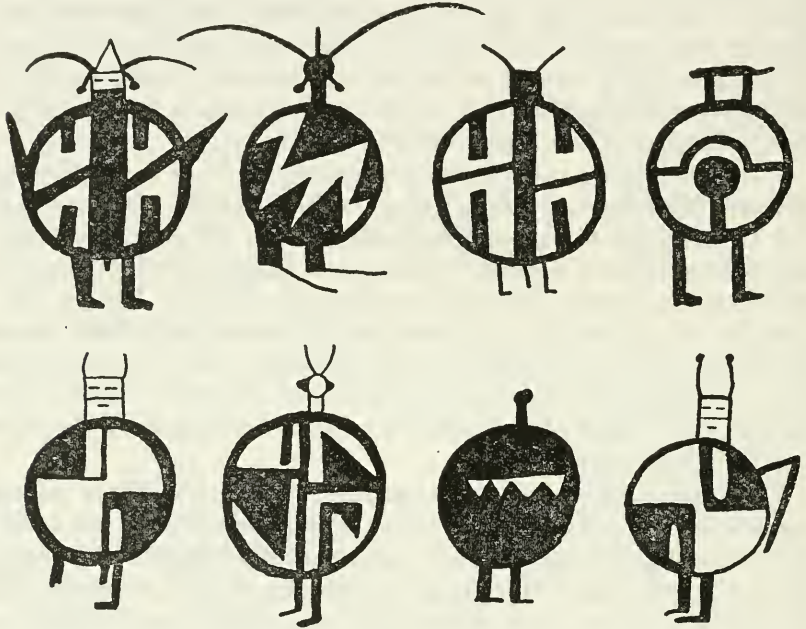
FIGURE 6.—Petroglyphs near ancient Pueblo cliff houses on the Colorado River in central Utah. These "men with shields" are about three feet tall.

it is impossible to know whether they are god-images, masked human beings, or simply bedecked ceremonial dancers.

In this same region there are other, cruder petroglyphs which may belong to a different period (pl. 9). These more or less resemble those of the Great Basin but tend more toward realism. Animals, birds, and human beings are common, some groups clearly depicting hunting scenes (pl. 9, A). These simple hunting groups and occasional rows of dancing figures (fig. 7) are among the few North American attempts at composition.

When the Pueblo Indians supplanted the Basket Makers in the Southwest, shortly after the time of Christ, the peculiar style of the former, which reached such excellence in Utah, died out in large measure in Arizona and New Mexico. Occasional anthropomorphic pictures occur on cave walls over or near cliff houses, and there are meanders and other figures resembling Pueblo pottery designs, birds,

horned toads or frogs, lizards, and occasional sheep and deer, most of which are drawn in a peculiar stiff and rectilinear style. Sometimes pictures are ornamentally painted on the wall plaster of house interiors.

An extremely interesting figure found in various parts of the Southwest and probably dating from an early prehistoric Pueblo period is a hunchbacked and very phallic individual (fig. 1, d), who plays a flute, usually lying on his back. It is interesting to note that one of the principal American Indian uses of the flute is in love making.

In view of the great amount of archeological research carried on in the Southwest our knowledge of petroglyphs is disappointingly meager. There are many petroglyphs which seem to be neither

FIGURE 7.—Carved petroglyphs of dancing figures, near Tucson, Ariz. Note that the artist became careless when making the figures on the left.

Basket Maker nor Pueblo, but their source remains a mystery. It is certain, however, that some drawings have been made down to the present day. The modern Pueblo Indians occasionally place symbols on the rocks, the Navajo and Apache sketch horses, men, and other simple and purposeless figures, and white men continue to put names and initials everywhere, often defacing older and irreplaceable native glyphs.

Southern California has many rocks bearing the complex and probably ancient geometric designs that characterize the Great Basin. The red zigzags and diamond chains (pl. 2, A), previously mentioned as the products of girls' puberty rites, are limited in distribution and are rapidly being obliterated by weather.

The regions of Santa Barbara and Tulare Counties, Calif., have a number of extremely interesting painted petroglyphs which have weathered so greatly during the past 25 years that their antiquity cannot be very great (pl. 2, B and C). These are usually very intricate geometric designs including "wheels", "targets", and other figures outlined by a solid or dotted line of a different color. There are also a few realistic or imaginary creatures, including many-legged insects, distorted and often spraddle-legged human beings, and quadrupeds in various awkward positions.

Despite the apparent recency of these petroglyphs, there is no way to know their meaning. Those near Santa Barbara bear a general resemblance to ground paintings made by some of the Chumash Indians during boys' initiation ceremonies, but it is idle speculation to suppose that this was their real purpose. The strange anthropomorphic and zoomorphic figures of the southern San Joaquin Valley were thought by some of the local Indians to have been doctors' marks, but this, too, is a guess and need not be accepted merely because an Indian made it.

Washington and Oregon have a great number of petroglyphs, a good portion of which are painted, but as the archeology of this general region is incompletely known and as the rock pictures have not been systematically studied, it is impossible at present to classify them according to age or area.

A large number of those which occur in or near the Columbia Valley are painted red and seem to be comparatively recent. Many are of human beings, apparently with feathered headdresses, others are of recognizable species of animals, including deer, sheep, and others. Many are strange zoomorphic creatures which may have been "water monsters" revealed to persons in visions or the guardian spirits of fishing places (pl. 12). Some figures even resemble those on certain carved stone and bone objects found in archeological sites and apparently dating from the past 200 or 300 years. Some of these have been published by William Duncan Strong and W. Egbert Schenck in Petroglyphs near the Dalles of the Columbia River, in the American Anthropologist, n. s., vol. 27, pp. 77–90, 1925.

There are many petroglyphs, both carved and painted in Idaho. The geometric and crude realistic figures found among the former are much like those of the Great Basin, to which they may be related. Others, including many that are painted, are of men, horses, and animals and often date from post-Columbian times. Because many of these bear a stylistic similarity to the pictographic writing of the Plains Indians who lived very close to this region, some people have been disposed to interpret them as pictographs. Perhaps many of these were true pictographic writing, but the interpretation of any particular petroglyph should be regarded with great skepticism. (See Richard P. Erwin, Indian Rock Writing in Idaho, in the Twelfth Annual Report of the Idaho Historical Society, Boise, Idaho, pp. 35–111, 1930.)

Petroglyphs east of the Rocky Mountains are not strikingly different from those of the west and comprise crude but frequently recognizable pictures of men and beasts, many wholly unintelligible geometrical scrawls, and the very common human and bear tracks. Many petroglyphs in Wyoming, South Dakota, Oklahoma, Colorado,

and New Mexico, perhaps dating from several periods and exhibiting marked local differences, have been published by E. B. Renaud in Pictographs and Petroglyphs of the High Western Plains, 8th Report of the Archeological Survey of the High Western Plains, University of Denver, 1936.

Starting soon after the arrival of European colonists in America, individual petroglyphs became the center of undeserved attention, so that to this day we have a voluminous argumentative literature concerning a few stones but virtually no broad, comparative studies which bring perspective into large areas. At various times the Dighton Rock, mentioned above, the Piasa petroglyph near Alton, Ill., and others have been discussed vehemently. Thanks, however, to Delabarre's efforts, a large bibliography on New England petroglyphs has been assembled. Donald Cadzow has added interesting material in Petroglyphs in the Susquehanna River near Safe Harbor, Pennsylvania, Publications of Pennsylvania Historical Commission, vol. 3, 1934. Petroglyphs from many eastern States were reproduced by Mallery.
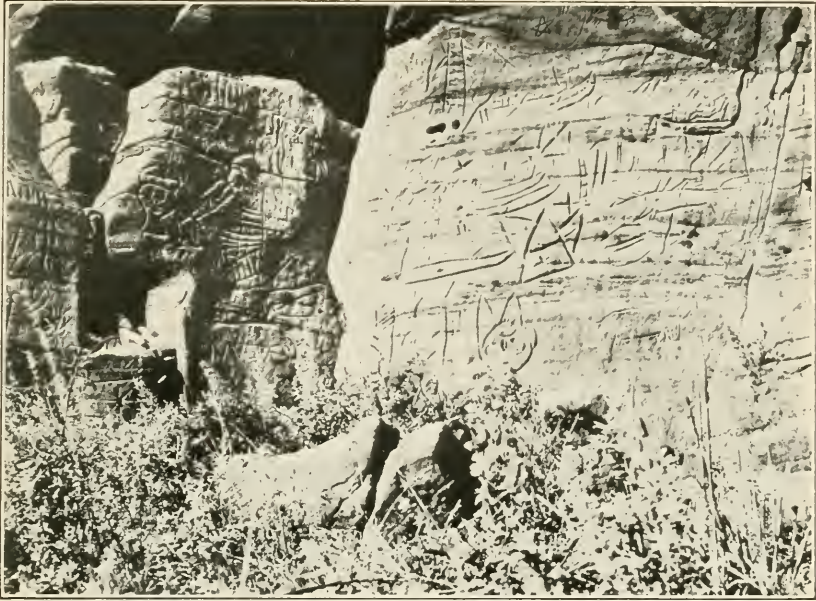
a, Petroglyph, perhaps pictographic in nature, near Smokey Hill River, Kansas. Note the boats in the upper right, proving the post-White origin of at least some of the pictures.

John O. Babbitt

b, Dighton Rock, Mass. Although probably the idle scrawlings of Indians, for three centuries these have been the subject of controversy.
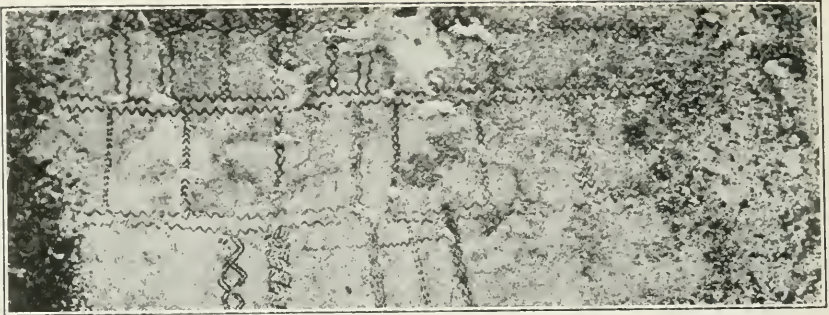
a, Pictograph in red in the San Jacinto Mountains, southern California, made during girls' puberty rites.
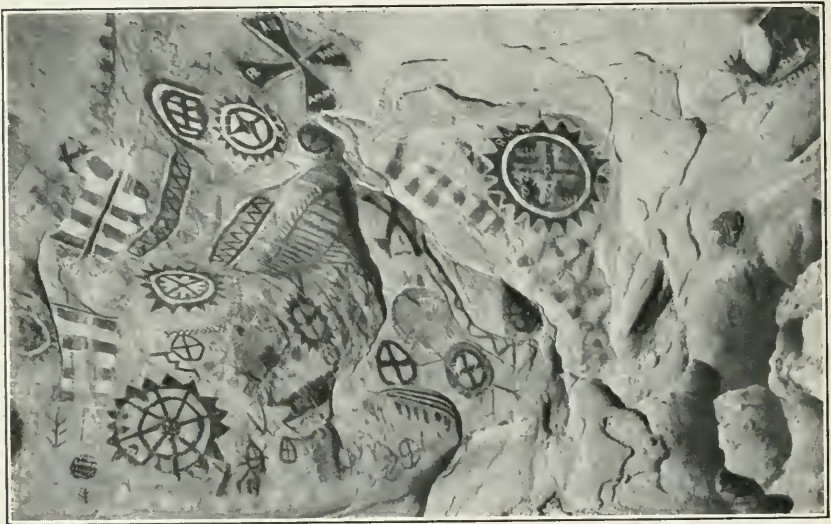
b, "Painted Cave" Santa Barbara, Calif. Designs of unknown meaning made in red, white, black, and brown.

c, "Carissa Rock", southern California. Painted designs which have nearly disappeared in 25 years.
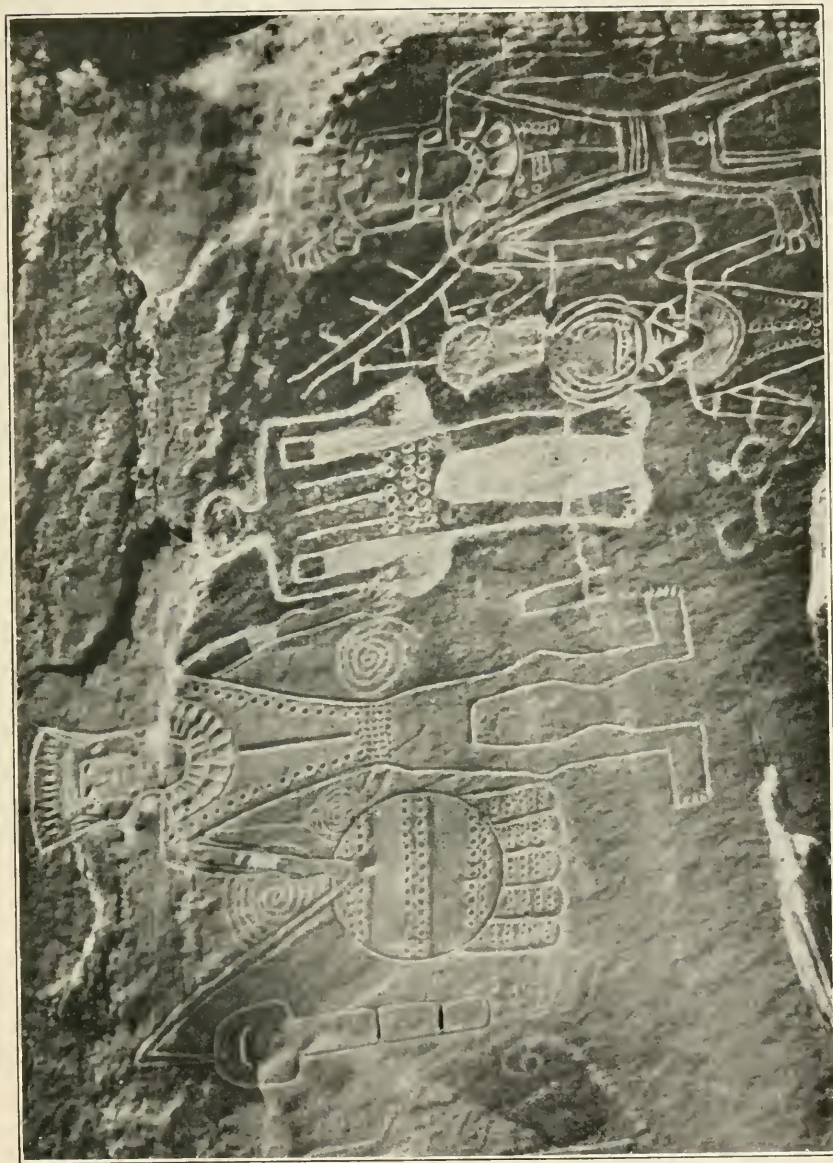
ANTHROPOMORPHIC, GODLIKE BEINGS, TWO OF WHICH ARE CARVED IN LOW RELIEF, NEAR VERNAL, UTAH.

This group is the finest in the United States.

a, Small red figure of the Basket Maker style, in a cave north of Great Salt Lake.
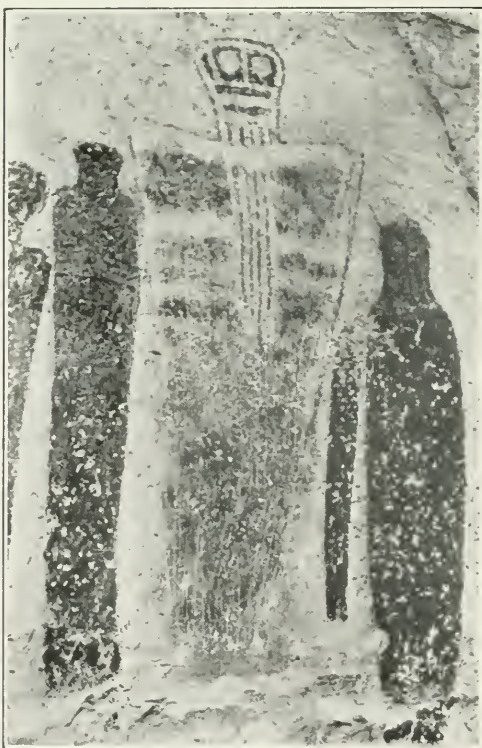
Dave Rust, Provo, Utah.

b, Godlike creatures in red and brown in Barrier Canyon. These are 6 and 7 feet tall.

ANTHROPOMORPHIC BEINGS IN UTAH.
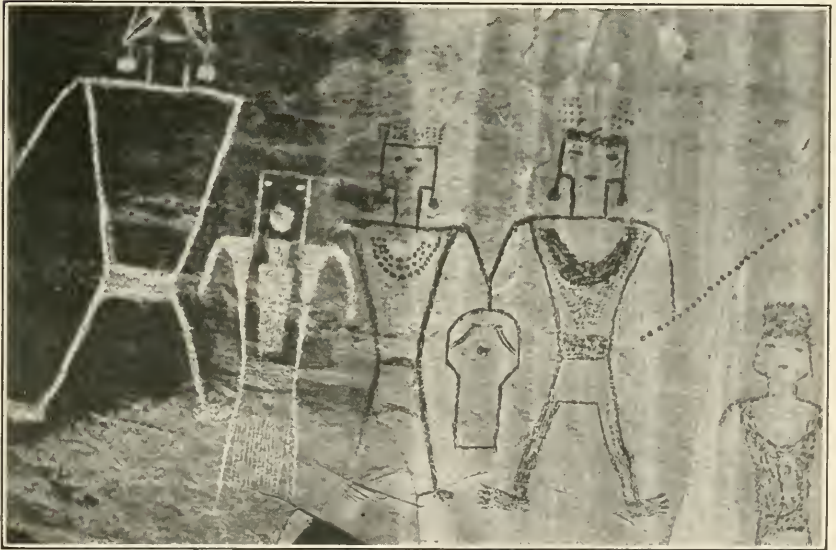
HUMAN BEINGS CARRYING HEADS, OR MASKS, NEAR VERNAL, UTAH.

PLATE 6

a, Pottery design used in red pictograph, 8 feet long, on cliff in Clear Creek Canyon, Utah.

Frank Beckwith, Delta, Utah.

b, Red maze in Fool Creek Canyon, Utah.

PLATE 7
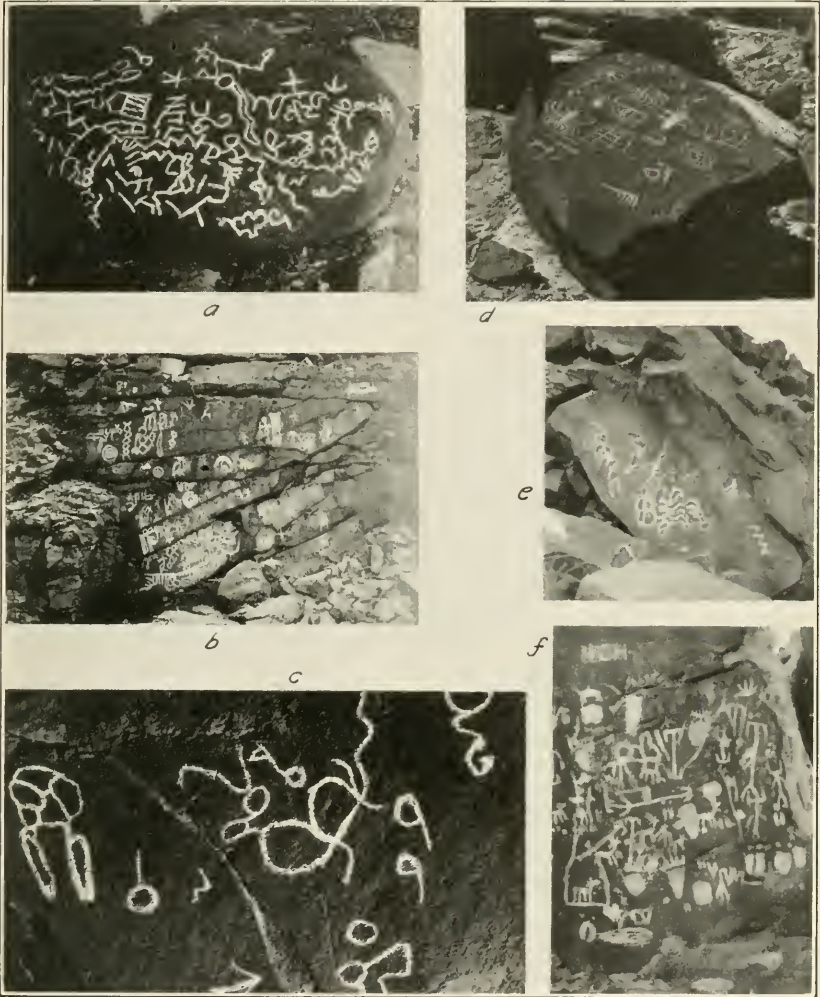
CARVED PETROGLYPHS OF THE CURVILINEAR GREAT BASIN STYLE.

a, b, Near Pyramid Lake, Nev. *c,* Northwestern Nevada. (Photograph by Ernest J. Greenwalt.) *d,* Near Lee's Ferry, Ariz. *e,* Deep Springs, Calif. *f,* Near Montrose, Colo. (Photograph by Arthur Monroe, of Montrose, Colo.).

PLATE 8
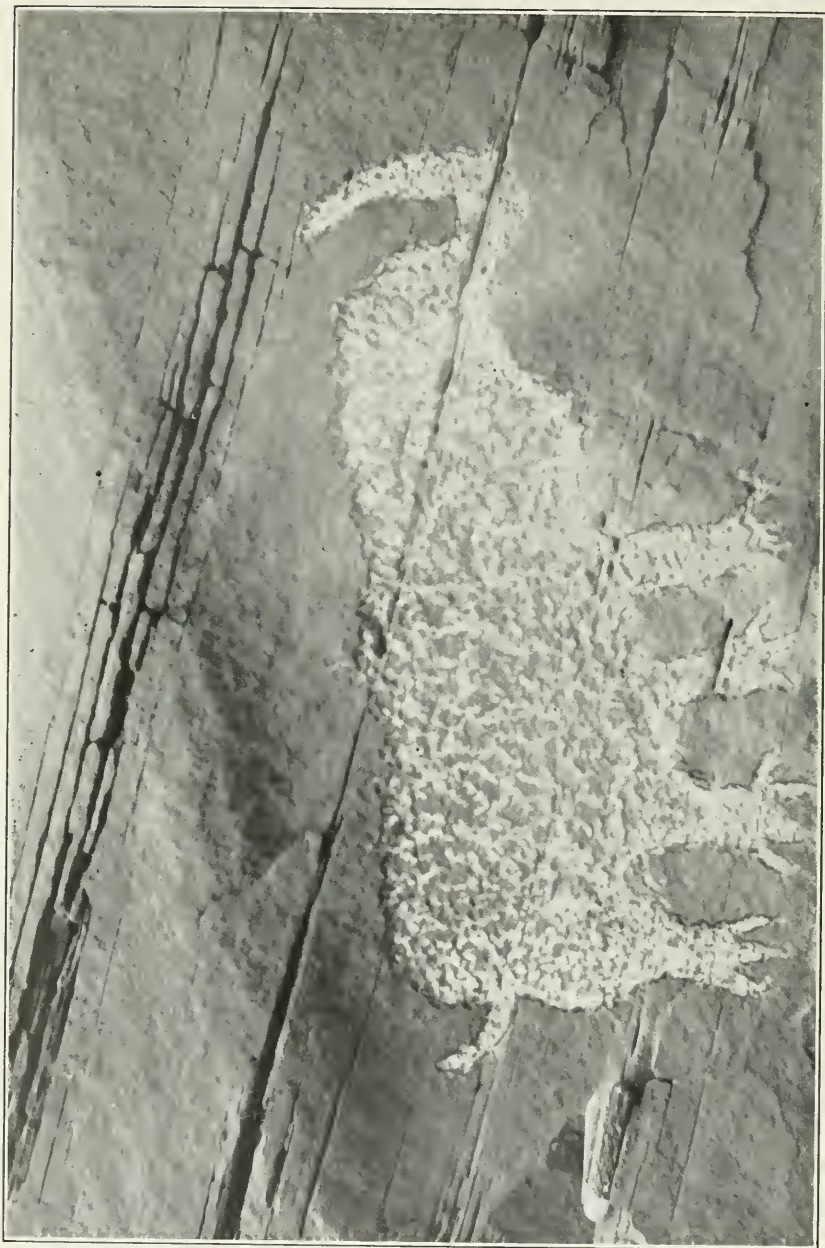
Charles Kelly

CARVED PETROGLYPH RESEMBLING A NOW EXTINCT ANIMAL.

The degree of retouching on this petroglyph is uncertain.
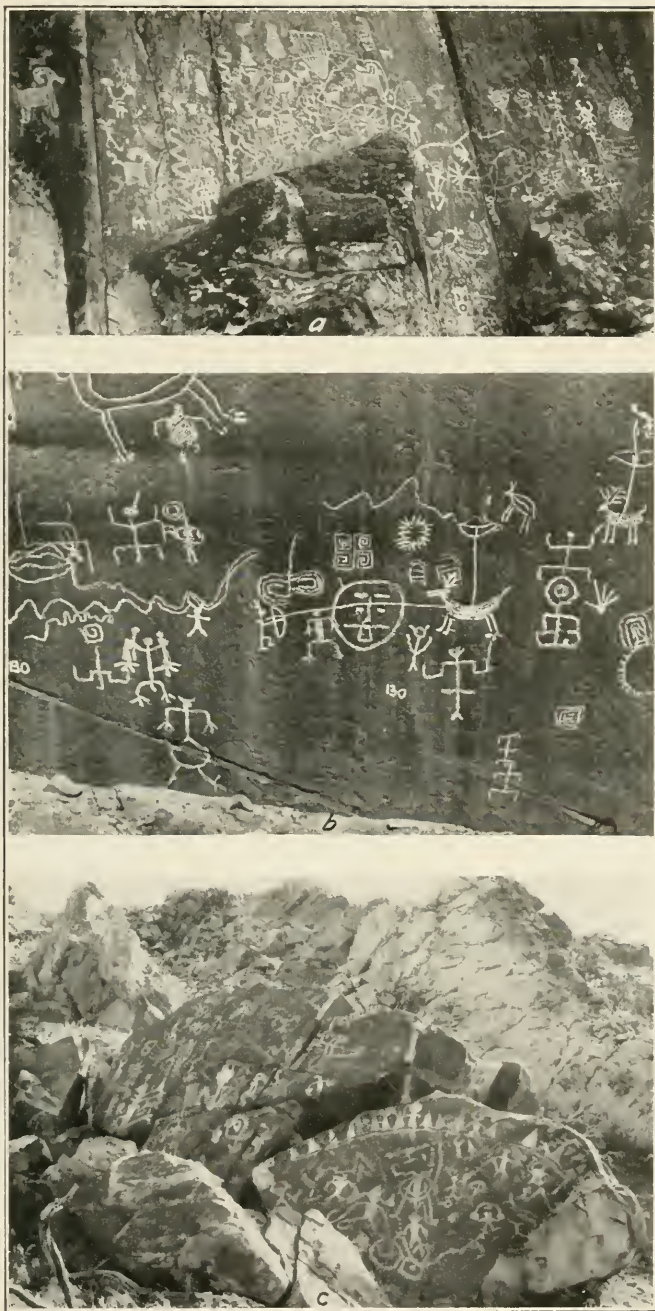
CARVED PETROGLYPHS IN UTAH.

a, Clear Creek. The superimposition of figures shows that this rock face was used over a long period. *b*, Hunting scene near Kanab. The representation of the bow and arrows shows that it was made by Pueblo or later Indians, for the bow was unknown in early Basket Maker times. The angular geometric figures are in Pueblo style. *c*, Untranslatable designs at Connor's Springs, north of Great Salt Lake. Although these seem to have been made recently and may be in part pictographic, it is impossible to know their meaning. (Photograph by Charles Kelly of Salt Lake City.)

PLATE 10
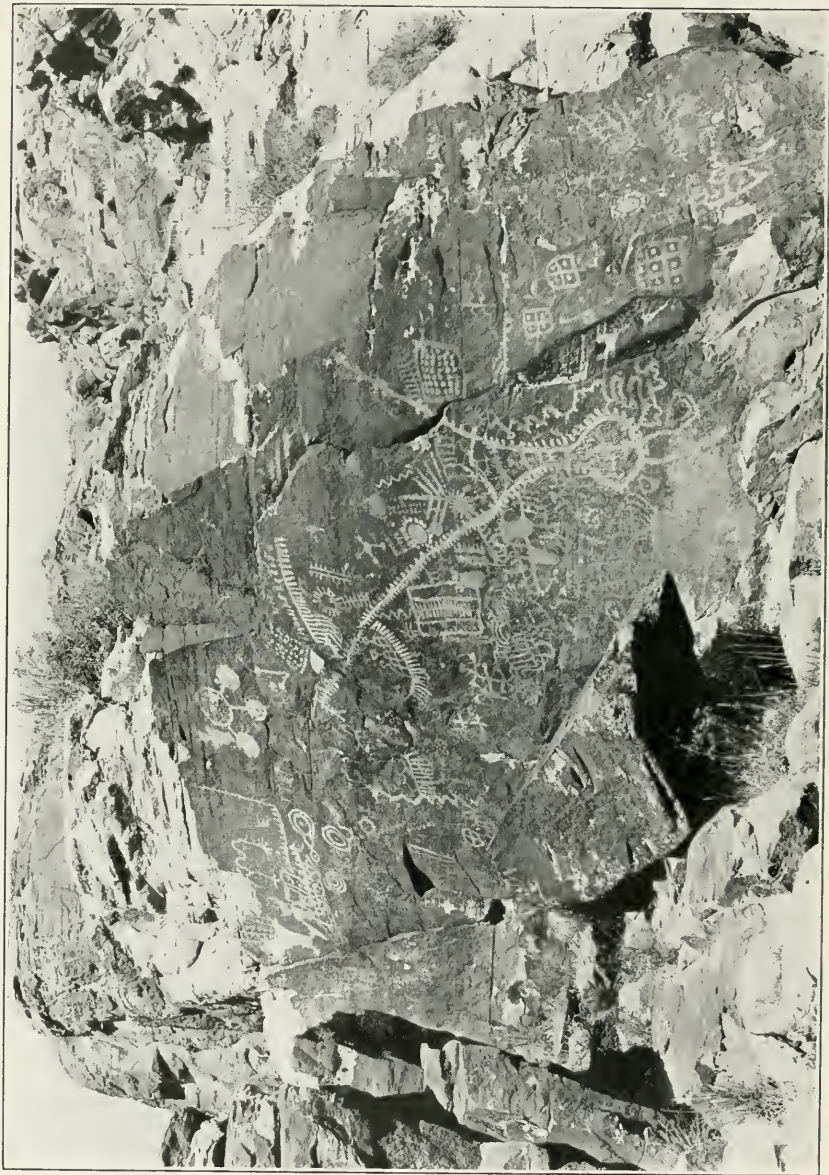
Frank Beckwith, Delta, Utah.

PETROGLYPH OF UNKNOWN ORIGIN IN WESTERN UTAH.

PLATE 11
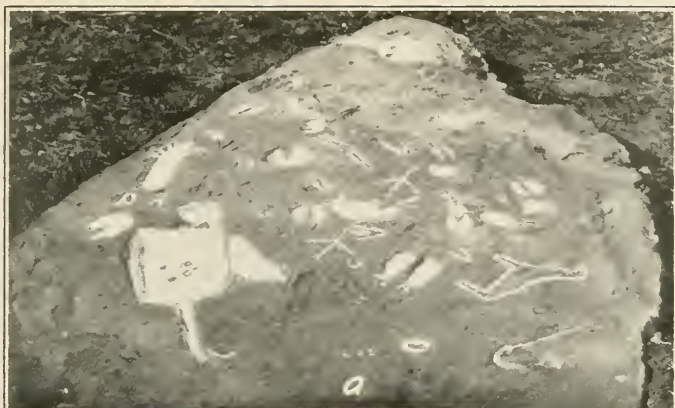
INDIAN PETROGLYPHS FROM EAST OF THE ROCKY MOUNTAINS.

a, "Medicine Rock." Carvings representing animal tracks near Liberty, Kans. *b*, Carved figures near Ambrose, N. Dak. *c*, Stone in Georgia.
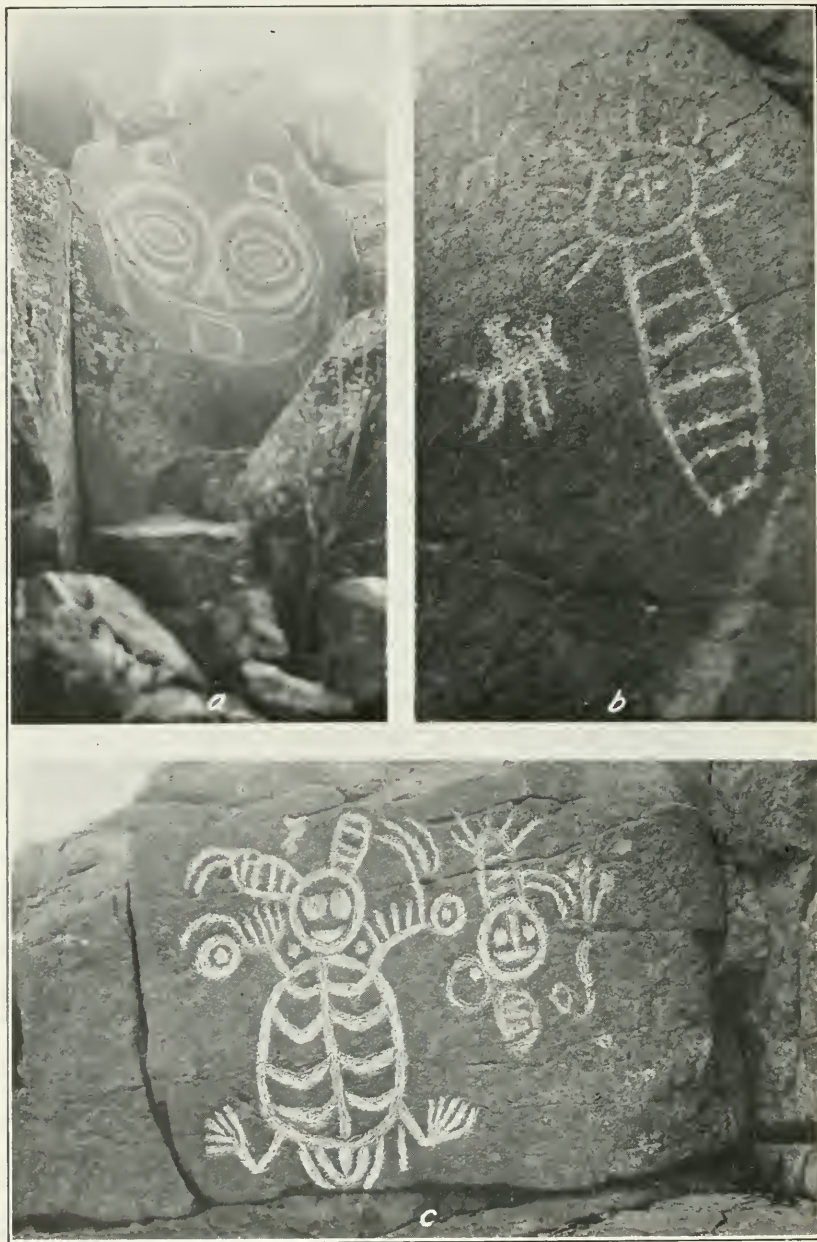
a, Isagiglalal, "She who watches you go by", a large petroglyph above the old Wishram Indian village at Spedio, Wash. (Photograph by W. D. Strong.) b, Supernatural being with sun disk for head, also mounted figure, both apparently made during the early historic period circa 1800, Petroglyph Canyon, near Spedio, Wash. (Photograph by W. D. Strong.) c, Large, deeply carved petroglyphs on rocks at salmon fishing station near the Wishram village at Spedio, Wash. They are said to represent the spirit guardians of the fishing places. (Photograph by C. F. Marshall, Portland, Oreg.)

THE HISTORY OF THE CROSSBOW, ILLUSTRATED FROM SPECIMENS IN THE UNITED STATES NATIONAL MUSEUM

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[With 6 plates]

A study of the crossbows in the United States National Museum suggests a problem of real ethnological interest. The crossbow appears to be another example of those remarkable Chinese inventions—such as silk, paper, printing, and gunpowder—which have spread over a large part of the globe and in several regions altered the course of history. The earliest mention of it occurs in Chinese texts dating from the third century B. C. It was extensively used as a military weapon by the Chinese several centuries before it was adopted by the Roman army. In Europe from the thirteenth to the sixteenth century it was the outstanding projectile weapon in all continental armies, and it materially aided the Spaniards in the conquest of Mexico, and De Soto in his discovery of the Mississippi. The crossbow is still extensively used by primitive peoples in southeastern Asia, and it even found its way into a small region in west Africa and among the Eskimo of Greenland and Alaska. This paper aims to describe the history and distribution of the crossbow as it is illustrated by the varied collection of both primitive and highly developed specimens in the United States National Museum.[1]

DESCRIPTION OF THE CROSSBOW

A crossbow is a projectile weapon equipped with a bow, but having in addition a stock set at right angles to the bow, and a string-catch which holds the bowstring in a drawn position until the weapon is shot. These three parts are all essential, but variations occur in each. For example, primitive people use a simple wooden bow (pl. 1) ; a more advanced stage is the compound bow of horn, sinew,

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and wood; and the final development, produced in Europe, is a great steel arc resembling a single carriage spring (pls. 4, 5). Again, the stock may be only a plain piece of wood, with or without a groove, on which the arrow rests. Sometimes it is cut away to avoid friction, as in pellet crossbows; and occasionally it is tubular, like a gun barrel.

Some primitive people can draw their crossbows with the hands alone, but in the powerful specimen from Cambodia (pl. 1, fig. 1) the native must put his feet against the concave side of the bowstave and strain at the string with all the muscular force of his arms, legs, and back. So powerful did the medieval crossbow become, however, that it could only be drawn by means of some extra mechanical device, sometimes resembling an automobile ratchet jack (pl. 5, fig. 2).

ORIGIN

The suggested origin of the crossbow deserving most consideration is the hypothesis that it developed from the self-acting bow-trap. This method of shooting animals is more widespread than the crossbow itself, being found in Asia, Europe, and Africa, from which latter continent it was brought by Negroes to America. The bow is set up horizontally on a support near some game trail. The problem is to keep the string drawn back until an animal walks into the trap. One common method is to have a string-catch attached to a stock set at right angles to the bow. Then when an animal disturbs the bait or passes in front of the bow it jerks a string connected to a trigger, thus firing the arrow at itself.[2]

Another form of the crossbow trap is illustrated on plate 2, where an Ainu specimen and one from Chinese Turkestan are shown. These are crude devices, but the three essential elements of bow, stock, and string-catch immediately mark them as a variety of the crossbow. The arrow does not leave the bow; rather, it pierces or stuns an animal which has set off the trigger while walking into the trap.

There is no real evidence, however, that the crossbow did actually develop from the bow-trap, and so the suggestion must remain only an hypothesis. It is to history and archeology that we must turn for dependable information concerning the early use and development of the crossbow after it had been specialized.

THE CROSSBOW IN CHINA

From China comes our earliest positive information. This rich field for historical and archeological investigation presents direct evidence for the crossbow during the second half of the third cen-

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[2] For a good article dealing with bow-traps see: Horwitz, Über die Konstruktion von Fallen und Selbstschüssen.

tury B. C. It is mentioned in historical literature composed at that time.[3] Probably it was known earlier, for the *Shih chi*, a work of great authenticity written about 100 B. C., on the basis of no longer extant documents, reports its extensive use during the fourth century in the battle of Ma-ling in 341 B. C.[4] From historical works produced during the Former Han Dynasty (B. C. 206–25 A. D.) it becomes amply evident that the crossbow was at that time the principal offensive arm of the foot-soldiers fighting on China's far-flung frontiers. Also there is one crucial statement in the *Shih chi* which tells specifically of the crossbow used as a trap. This passage describes the tomb of the great emperor Ch'in Shih, who died in 210 B. C. In supervising the preparation of his own sumptuous tomb "he commanded the artisans to make automatic crossbows and arrows so that if anyone dug in and entered they would suddenly shoot and slay them."[5]

Within recent years archeology in China and neighboring countries has been revealing unknown secrets of the brilliant civilization of Han times. Parts of crossbows left by the imperial Chinese troops of 2,000 years ago have been found in northern Korea, southern Manchuria, Inner Mongolia, and even in the desert waste of Chinese Turkestan. Along the old frontier limes in eastern Central Asia, Sir Aurel Stein discovered 2,000-year-old guard stations which had once been used by the defenders of China's silk route to the West. In the rubbish heaps he found army ordnance lists, written in still legible characters on wooden slips. In these documents crossbows are mentioned, together with their strings and arrows, some 30 times, while the plain bow is mentioned only twice, in each case in the hands of a "barbarian".[6] This proves almost conclusively that the crossbow was the standard offensive projectile arm of the Chinese frontier troops during the first century B. C. and during the first few centuries A. D. It may have been this effective weapon which gave the

[3] *Han Fei tzŭ*, chüan 18, p. 9; and the *Chan kuo ts'ê, Han ts'ê*. For the sake of caution I am not yet willing to cite as authentic a section of the *Mo tzŭ*, book 14, "On fortification and defense", which may perhaps date from the fourth century B. C. This section is studded with references to various types of crossbows. Of an entirely different nature is the critical problem regarding the date and authenticity of the *Chou li*, which also mentions various kinds of crossbows. At one time this work was thought by many western Sinologists to date from about 1100 B. C., and owing to this error Forke (Ueber die chinesische Armbrust), and Horwitz (Die Armbrust in Ostasien) have created the impression that the crossbow was much earlier known in China than we now have any reason to believe.

[4] Edition of Takigawa, Kametaro. *Shiki Kaichu Kōshō*. Tokyo, 1934. Chüan 65, *Sün-tzŭ Wu-ch'i lieh-chuan*, p. 11. Cf. also Chavannes, Edouard. *Les Mémoires Historiques de Se-ma Ts'ien*. Paris, vol. 5, p. 155, 1895–1905.

[5] *Shih chi*, op. cit., chüan 6, *Ch'in Shih Huang pên-chi*, p. 69; and Chavannes, op. cit., vol. 2, p. 193. The translation is my own.

[6] See: Stein, Aurel, Serindia, vol. 2, pp. 758–759, Oxford, Clarendon, 1921; and Chavannes, Edouard, Les documents chinois découverts par Aurel Stein dans les sables du Turkestan Oriental, pp. xv–xvi, Oxford, 1913.

Chinese a slight advantage over their wild, horse-riding, bow-shooting enemies on the north.

There are also in existence numerous bronze trigger blocks from crossbows of Han date (pl. 3). From these the exact mechanism for cocking and firing the crossbow can be studied. Even the date of manufacture is incised on some of these specimens: the earliest such inscription of which I am aware was written in 65 B. C. Of course, some of these inscriptions may be forgeries, but fortunately it is not necessary to depend upon them for dating these bronze trigger blocks. In northern Korea many graves of an old Chinese colony have been scientifically excavated by Japanese archeologists, and in one such tomb dated as 7 B. C. a bronze trigger block was discovered. In another tomb, thought to date about 150 A. D., a complete crossbow was found, with bow, stock, and bronze trigger mechanism all excellently preserved.

Thus, there is abundant evidence for the crossbow in China dating in literature back to the third century and in actual remains to the first century B. C.

SIEGE ENGINES AND THE CROSSBOW IN THE CLASSICAL WORLD

Probably the only other region where the crossbow was known in comparatively early times was the Greco-Roman world. Did it go from China to the Mediterranean, or was the invention diffused in the other direction? This fascinating question is not easily answered; some of the evidences for its early use in the classical world are presented here without conclusions.[7]

There seem to be no archeological reports of the crossbow before the fifth century A. D. from the ancient Mediterranean world— that is, the region comprising Greece, Syria, Asia Minor, Egypt, Carthage, and Italy. Literary records alone help in the problem and they are far from decisive. They refer, for the greater part, to missile-throwing siege engines, which were certainly not hand weapons. These engines were the catapult and the ballista. Although in some respects resembling the crossbow, they work on a different principle, deriving their main power from torsion, not tension.

To get a picture of these engines, imagine looking into a long timbered box without front or back, set up horizontally on a stand. This box has three divisions made by two upright pillars, and through the central section runs a long grooved stock set at an upward slant. On the lower end of this stock are a string-catch and

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[7] The following notes are presented with deference because I am not conversant with many of the problems of historical criticism surrounding Hellenistic and Roman texts.

trigger. In each of the two side partitions is a thick skein of human hair or animal sinew fastened vertically through holes in the top and bottom of the frame. A crank above the left skein twists it counterclockwise; another above the right, clockwise. Fixed into each skein are half bowstaves which, because of the force of torsion, stick out at right angles. A bowstring is fastened from the outward end of the left bow-arm to the outward end of the right, and when this string is drawn back by means of winches to the string-catch on the stock, the engine resembles a huge drawn crossbow. Because of the combination of torsion in the skeins and tension in the arms it is much more powerful.[8]

The catapult or ballista, unlike the crossbow which was manipulated by one man only, was a piece of artillery operated by a crew. These machines stand in relation to the crossbow somewhat as the cannon stands to the hand gun, itself developed later than the cannon. But the functional and chronological relationship between the crossbow and these siege engines is not clear: the crossbow may have preceded and suggested them; it may have developed in the classical world from them; or, it may have no fundamental relation whatever to them, possibly having been introduced from some other region, such as China.

The arrow firing catapult is said to have been invented in Syracuse and first used in war by Dionysius I of Syracuse against Carthage in 397 B. C.[9] A catapult arrow was exhibited as a curiosity in Sparta in 370 B. C., and an inscription mentions two catapults at Athens about 358–354. In 341 B. C. they were used extensively in the siege of Byzantium both by Philip of Macedon and by the defenders. Alexander the Great promoted the use of all kinds of siege engines. His engineers developed especially torsion catapults, which he took with him on his campaigns all over western Asia and as far east as the Juxartes River. From his time on they were used in nearly every important siege even down to fairly recent times.

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[8] Reconstructed specimens of these machines are illustrated in the articles by Gohlke, Payne-Gallwey, and Schramm. Ancient representations of the actual machines may be seen on a Roman tombstone, dating around 77 A. D., figured in Jones, Companion to Roman history, pl. 38; and on the column of Trajan, built 105–113 A. D. Cf. Froehner, Wilhelm, La Colonne Trajane, pl. 90 and detail pl. XVII. Paris, Rothschild, 1872–74. In these bas-reliefs the details, naturally, are not very clear. Both Schramm and Payne-Gallwey actually made models to test out the literary accounts of antiquity.

[9] An excellent account of the history of catapults is found in a work by the leading English authority on the Hellenistic period: Tarn, W. W., Hellenistic military and naval developments, p. 103 ff., and I have followed him in this paragraph. Other good accounts are in Jones, op. cit., pp. 215–223; Payne-Gallwey (both works); and Schramm, E., Poliorketik. This latter is essential as it assembles the available historical references in Greek.

Returning to the crossbow itself: most modern historians assume that the catapult developed from it. However, there is only one bit of historical evidence supporting this belief. This is to be found in a work on the manufacture of darts written by Heron of Alexandria, who lived perhaps sometime between 285–222 B. C., or else during the second century B. C. He ascribes the invention of a certain weapon to one Zopyrus, who, he indicates, lived in Tarentum about the beginning of the fourth century B. C. This weapon Heron called the *gastraphetes* or "stomach bow", because it was spanned by pressing the butt of the stock against the stomach. From his description it appears to be a crossbow, and he considered it an evolutionary step between the bow and the catapult. Whatever this weapon was, it is never mentioned by classical military writers and apparently played no part in warfare.

The great column of Trajan, erected in Rome between 105 and 113 A. D., has scores of battle and camp scenes depicting Roman and Dacian soldiers using all kinds of arms—swords, axes, slings, bows, catapults, etc.—but does not show one crossbow.[10] The first classical writer on military affairs specifically to mention its use as a military weapon is F. Vegetius Renatus (fl. A. D. 386). In his "*De Re Militari*" (II, 15; III, 14; IV, 21, 22) he mentions crossbows and crossbowmen as a regular part of the Roman army, but he does not describe them, apparently because they were already well known. It appears, therefore, that sometime between the beginning of the second century and 386 A. D. the crossbow first became a regular part of Roman military equipment. The first actual representations of Roman crossbows now extant are seen on two monuments in France dating, perhaps, from the fifth century A. D. One is on a tomb column at Polignac sur Loire, and the other is figured in a painting from the walls of a Roman villa at Puy.

Thus, we see that siege engines resembling the crossbow are reported in the West about 400 B. C., and a weapon which may well have been a crossbow is mentioned by a writer in Alexandria who lived during the third or second century B. C. Crossbows are first definitely mentioned as a regular weapon in the Roman army toward the end of the fourth century A. D. We are faced, then, with three historical possibilities: The crossbow was independently invented in the two regions of China and the classical world; it was invented only once, and spread from China to the west, or, less probably, in the other direction; and, finally, it may have been invented in a third region somewhere between the two and then been diffused in both directions, to be eagerly seized upon in China and almost neglected in the west.

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[10] Compare: Froehner, op. cit., plates.

Both China and the classical world did, indeed, derive numerous weapons, items of equipment and military systems from the region lying between—that area including Persia, northern India, south Russia, and Central Asia. But apparently the crossbow was not one of these. It is not reported from the extensive excavations of Scythian and Sarmatian graves around the north and east of the Black Sea; nor would it be likely to develop among those nomadic people who so skillfully handled the bow on horseback, and for whom the crossbow would be a cumbersome weapon offering few advantages. Likewise, their cousins in culture, the Hsiung-nu, another nomadic people, living to the north and northwest of China, did not use the crossbow, though they regularly found it employed against them by stalwart Chinese foot-soldiers. I cannot find it mentioned or figured as a weapon employed by the Achaemenid and Seleucid Persians, nor among the Parthians, who maintained their kingdom from B. C. 248 to 226 A. D. And it can probably be ruled out for northern India, since it is not mentioned in the graphic accounts of Alexander's campaign there; nor is it depicted among the weapons figured on Indian coins, or on the topes of Sánchi (first century A. D.), Amravati (some 300 years later), and on the hill caves of Orissa, dating 200 B. C. to 474 A. D. So it seems there is nothing but negative evidence for the whole region of Central Asia and the Near East; but this is supported by the positive evidence that even after the crossbow was well known in those regions, it was never wholeheartedly adopted in preference to the indigenous powerful composite bow.

THE CROSSBOW IN EUROPE

The Middle Ages in Europe saw the crossbow at its greatest development. The Museum has two excellent specimens made in Germany during the fifteenth and sixteenth centuries (pls. 4, 5). Beginning in the tenth century, shortly before the Crusades, the "arbalist" or crossbow begins again to appear in Europe. There is actually some evidence that the Saracens may have introduced it. From 1200 to 1480 it developed rapidly, progressing through several stages to become a powerful and deadly weapon.[11] At first the bow was of the compound sort, made of horn or whalebone, yew, animal tendon, and glue. During the fourteenth century, however, a powerful arc of steel was introduced which necessitated an extra contrivance to draw it. Earlier ones, such as the larger specimen figured (pl. 4, fig. 1), had a metal stirrup fixed to the front end of the stock, and the crossbowman placed one or both feet in this stirrup. Attached to a belt around his waist he had a heavy leather thong and a pulley which he fastened by a hook to the bowstring. This system reduced

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[11] Full details of the development of the crossbow in Europe are given with illustrations in: Payne-Gallwey, The crossbow.

the weight of the pull and also allowed him to exert the full power of his legs and back in the draw. As the steel bow developed in thickness and strength better spanning mechanisms were invented. The windlass was one of these, and consisted of sets of pulleys and ropes wound up by a pair of handles fixed to the back of the stock. Another was the "goat's foot", which, acting on the principle of the lever, pried back the bowstring. This was the only satisfactory mechanical spanner for mounted crossbowmen.

In warfare the crossbow had its advantages and disadvantages in relation to the plain bow. It had more range and power, shot a more deadly missile, could be sighted more accurately, and be drawn ahead of time and fired on an instant's notice. On the other hand, it was cumbersome, frequently weighing up to 16 pounds, and it could not be repeatedly drawn and fired rapidly. Therefore, the perfected crossbow of the Middle Ages was at its best in defending a fortress where it could be aimed from a parapet, drawn in a small space, and where its tremendous power, range, and accuracy made it a superb weapon for defense. The longbow excelled in open battle, for the archer could shoot half a dozen arrows while the crossbowman was drawing his bow and fixing his bolt for the next shot. This was strikingly proved in the Battle of Crécy in 1346, where, on an open field, the English longbowmen won a decisive victory over the pick of European crossbowmen, the Genoese.

Toward the end of the fifteenth century, just when the crossbow was beginning to give place to the arquebus as a military weapon, there was developed the elaborate sporting crossbow with its mechanical spanner known as the "cranequin." A beautiful specimen, probably dating around 1550, is seen in the National Museum collection (pl. 5, fig. 1). It was too expensive and too slow for military use, but was popular for a century and a half among sportsmen. In hunting larger game they much preferred this silent and reliable weapon to the noisy and erratic hand gun.

Many other parts of the crossbow, such as the sights, trigger, arrow groove, and various types of arrows and bolts, underwent technical development, too. Space does not allow more than a mention of the "prodd" or "arbalète a jalet", a two-stringed crossbow for shooting stones and pellets, introduced about 1500.[12] Concurrently there appeared the "slurbow" in which the stock was mounted with a wooden or metal barrel to hold the missile, and slotted lengthwise for the string. (A primitive slurbow from Simalur Island, south of Sumatra, is figured on pl. 1, fig. 2.)

[12] The National Museum contains specimens of the plain pellet bow, without a stock, from Siam. Oddly enough this two-stringed pellet bow is also used by the natives of South America.

One other part has especial historical interest: the string-catch mechanism. In medieval crossbows this is a revolving spool of horn set down into the top of the stock near the middle, and held in place by a transverse pin. (See pl. 4, and also pl. 5, where they are shown separately in figs. 3, 4.) The upper edge of the spool is cut with a transverse notch for the string, and at right angles to this there is another notch in which the butt of the arrow fits tightly. On the under side of the spool is a small pit into which the upper end of the trigger fits snugly. The bow is drawn and the string fixed behind the catch; then an arrow or bolt is placed on the stock with its butt end held tightly by the two fingers of the spool. As soon as the trigger is drawn, however, the spool tumbles forward under the pressure of the bowstring, which is thus released and the arrow shot. This practical device was not improved upon, and is even seen, made of hardwood, in the recent sporting crossbow in the National Museum collection (pl. 4, fig. 2, and pl. 5, fig. 4).

It is a striking historical fact that at least as early as the first century B. C. this essential device had been perfected by the skillful Chinese mechanics of the Han empire. There it was cast in bronze, and the several parts of the mechanism fitted together with admirable precision. It is more elaborate and differs in some details, but the close resemblance between the early Chinese and later European device strongly suggests that we may some day discover that this apparatus is a Chinese invention which found its way into Europe (pl. 3).

WORLD-WIDE DIFFUSION OF THE CROSSBOW

Toward the end of the fifteenth century began that great series of voyages which opened the whole world to European adventurers and traders. At that time the hand gun or "arquebus" had not yet been perfected, and many explorers carried the old-fashioned reliable crossbow among their stores of arms.

Vasco Da Gama took crossbows with him around the Cape of Good Hope in his discovery of the ocean route to India in 1497–98, and had to use them against natives on the East Coast of Africa. In the conquest of Mexico Cortèz had more crossbows than arquebuses, and on one occasion when all the gunpowder blew up he had only his crossbows to depend upon. De Soto's infantry were about equally armed with crossbows and guns in the exploration from Florida to the Mississippi. In a battle in 1539 the necessarily slow manipulation of the crossbows showed up badly against the Indians, who could discharge three or four arrows while the crossbowman could shoot once. David I. Bushnell, Jr., informs me that only a few decades ago Mooney found some old English [or more probably

Spanish] crossbows still preserved as cult objects by the Indians in North Carolina.

It is this last great spread of the crossbow that probably explains its sporadic use among the Fans of the Gaboon, and their southern neighbors in the Cameroon. Balfour has adduced reasons for believing that it was brought there by Dutch or Danish navigators during the latter part of the fifteenth century;[13] but it would seem historically more probable that the Portuguese did so. Dutch and Norwegian whalers probably introduced the toy crossbow to Greenland in the seventeenth or eighteenth century.[14] From there it may have spread along the Arctic regions of North America, and those found in use among modern Eskimo boys in Alaska may be a result of this diffusion; or they may have got them from Russian traders from the Pacific.

CHINESE REPEATING CROSSBOW

The remarkable Chinese repeating crossbow in the National Museum collection (pl. 6) deserves special description in this historical section. This clever invention has a magazine above the stock with room for 20 arrows, which may be rapidly fired in pairs. The bowstring passes through a slot running along the bottom of the magazine (pl. 6, fig. 1). When the magazine is pushed forward by its handle, the string is caught in the back of the slot, and two arrows fall into place. As the handle is drawn back this automatically draws the bow (pl. 6, fig. 2); when it comes clear back, so that the magazine rests squarely on the stock, a little pin pushes the bowstring up and releases it, firing the arrows. This process can be repeated so rapidly that 10 pairs of arrows may be fired in half a minute. Although this type of crossbow is not very powerful, a barrage of arrows, especially if they were poisoned, might have a demoralizing effect on the enemy.

This repeating crossbow is illustrated at least as early as in the *Wu pei chih*, a Chinese work on military science published in 1621, but it is probably much older. Yet it was used even as late as 1895 by Chinese troops from the interior in the war with Japan. Needless to say, it was useless against an enemy fully equipped with modern arms.

DISTRIBUTION OF THE CROSSBOW

The true home of the crossbow is the great land mass embracing the continents of Europe and Asia. Specimens in the National Museum collection come from an island south of Sumatra, the Philip-

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[13] Balfour, Henry, The origin of west African crossbows.
[14] Thalbitzer, William, ed., The Ammassalik Eskimo. Medd. Grønland, vol. 39, p. 471, 1914.

pine Islands, Cambodia, the Nicobar Islands, China, and Siberia; from the West are two examples from Germany and a modern sporting crossbow of unknown origin.

In the southeastern tip of Asia, an ethnological backwash of the continent, primitive peoples still use the crossbow extensively in hunting and warfare. This wild region, extending from Bengal in eastern India through Assam, Burma, Siam, and French Indo-China, and reaching up into the southwestern Provinces of China proper, is one of the last strongholds of the primitive way of life. To the north lies China, where the crossbow has been continuously known for more than 2,000 years and where it had a remarkable development as an engine of war. From China it passed into Korea, then into Japan, but neither country accepted it wholeheartedly in preference to the bow. The Yakut, Lamut, Tungus, Yukaghir, Koryak, and Chukchee peoples of Siberia know it as a weapon and a toy, but use it primarily as a trap. Finally, those mysterious people, the Ainu, isolated in the northern tip of Japan, know it only for trapping game. In the sixteenth century it was used in Central Asia and northern India by the Persians. The Roman legions employed it in the fourth century A. D. In all continental European armies, from about 1200 to 1500, it was used extensively until gunpowder made it obsolete for warfare. Far from its true home the crossbow was also adopted in West Africa, Greenland, and Alaska.

Many unknown gaps still exist in the history of the crossbow's wide diffusion from whatever center first specialized it as an efficient weapon for hunting and warfare.

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PLATE 1
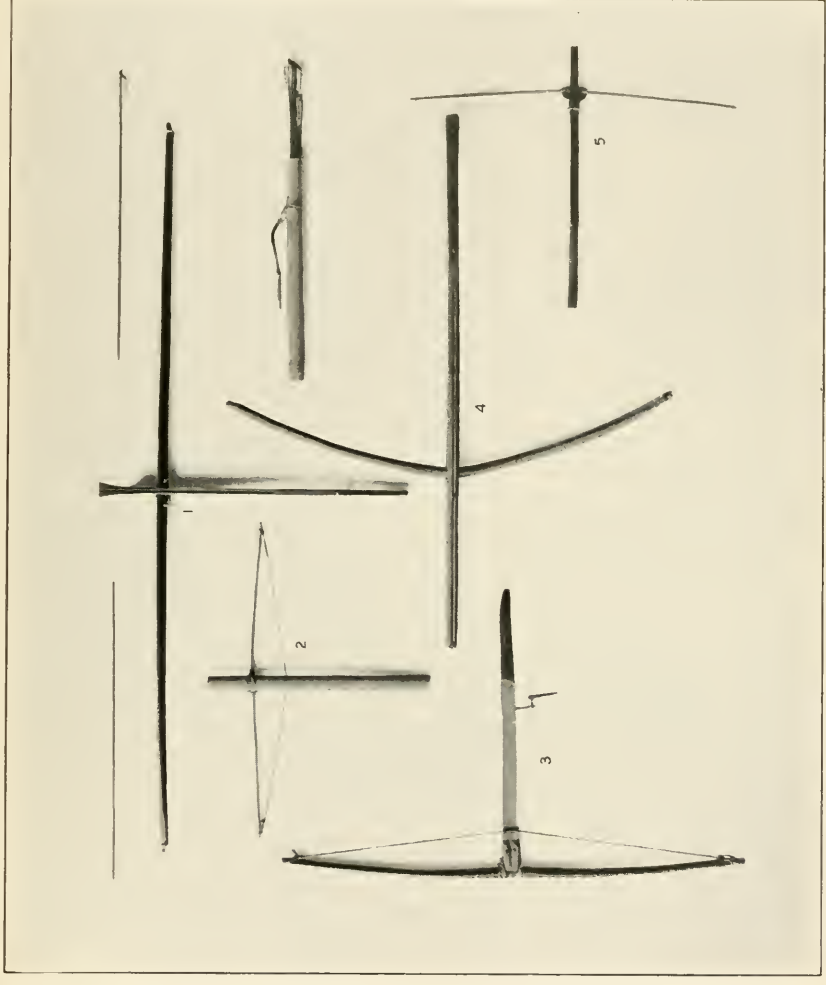
1, CROSSBOW WITH ARROWS AND QUIVER, ANGKOR TOME, CAMBODIA; 2, SLURBOW, SIMALUR ISLAND, SOUTH OF SUMATRA; 3, CROSSBOW, CHUKCHEE, EASTERN SIBERIA; 4, CROSSBOW, CAR NICOBAR, NICOBAR ISLANDS; 5, CROSSBOW, PHILIPPINE ISLANDS.

PLATE 2
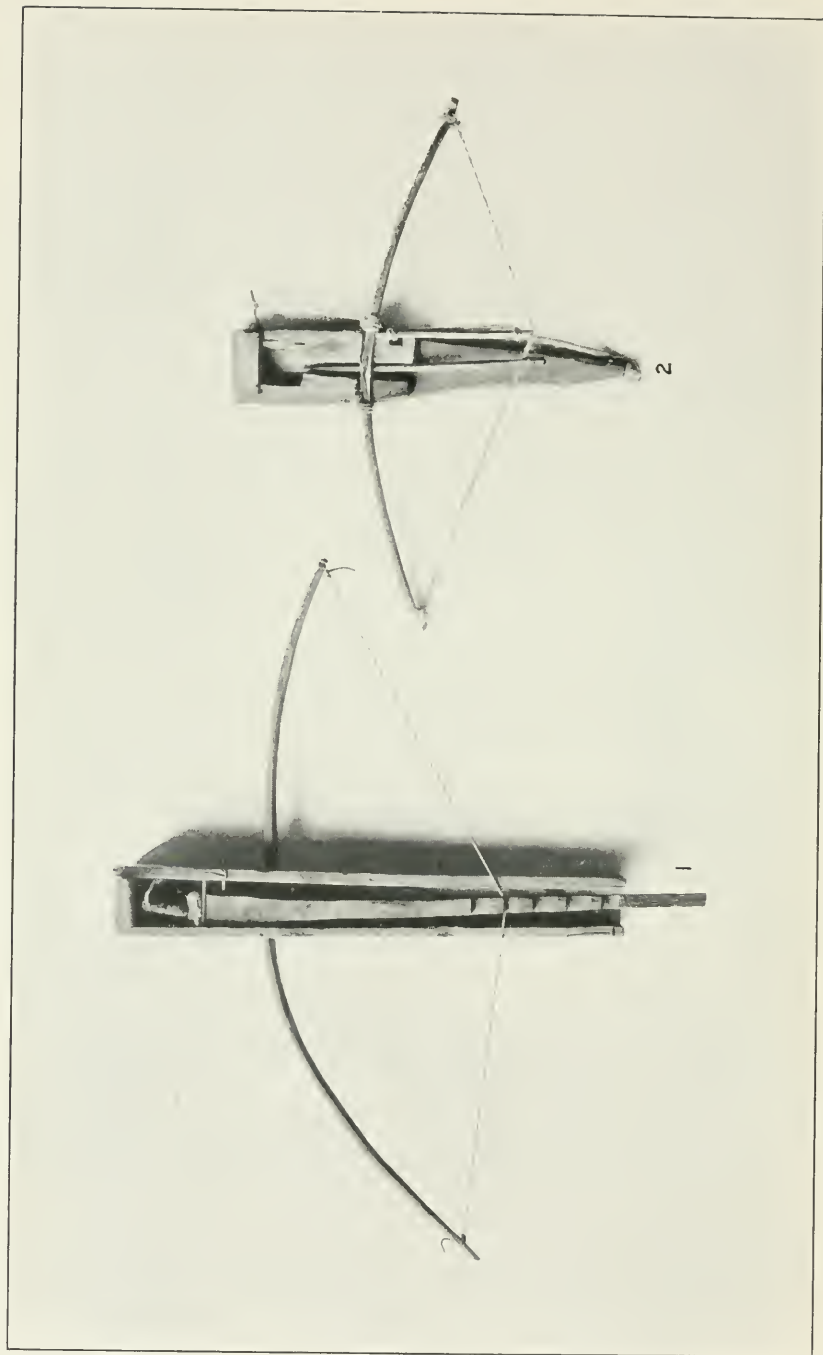
1. CROSSBOW TRAP, PIRATORI AINU, HOKKAIDO, JAPAN; 2. CROSSBOW TRAP, EASTERN TURKESTAN.

PLATE 3
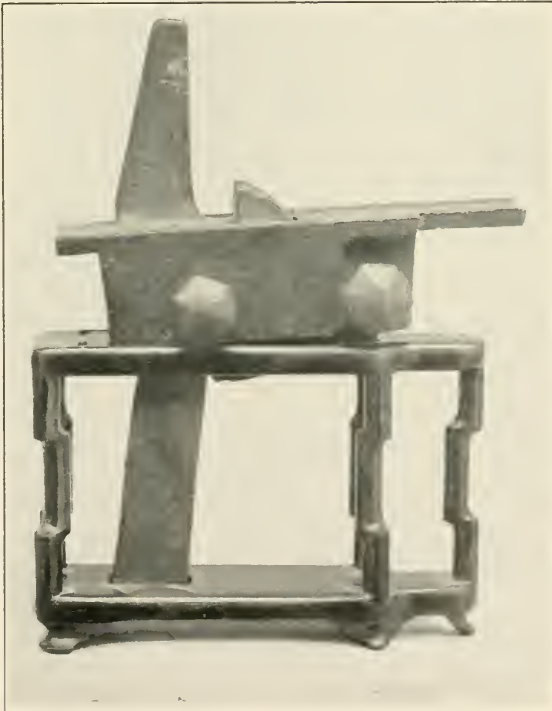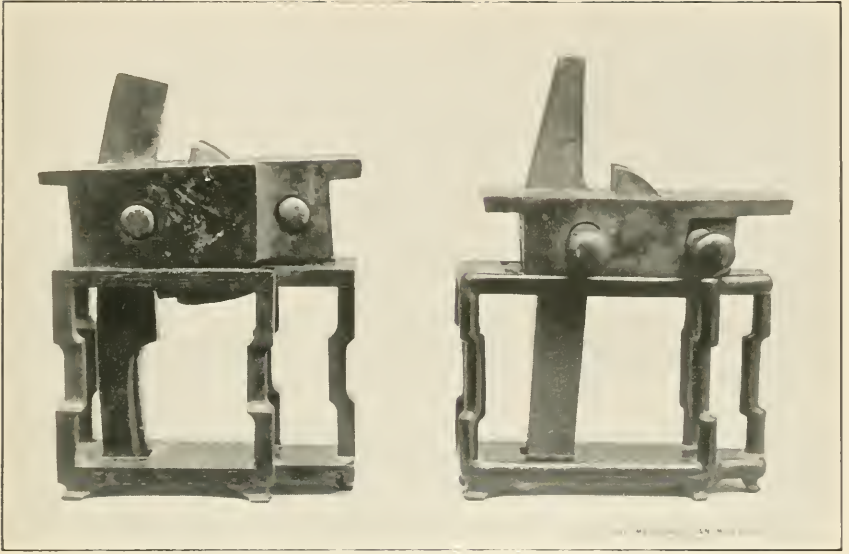
Metropolitan Museum of Art.

BRONZE TRIGGER BLOCKS FROM CHINESE CROSSBOWS OF HAN DATE.

PLATE 4
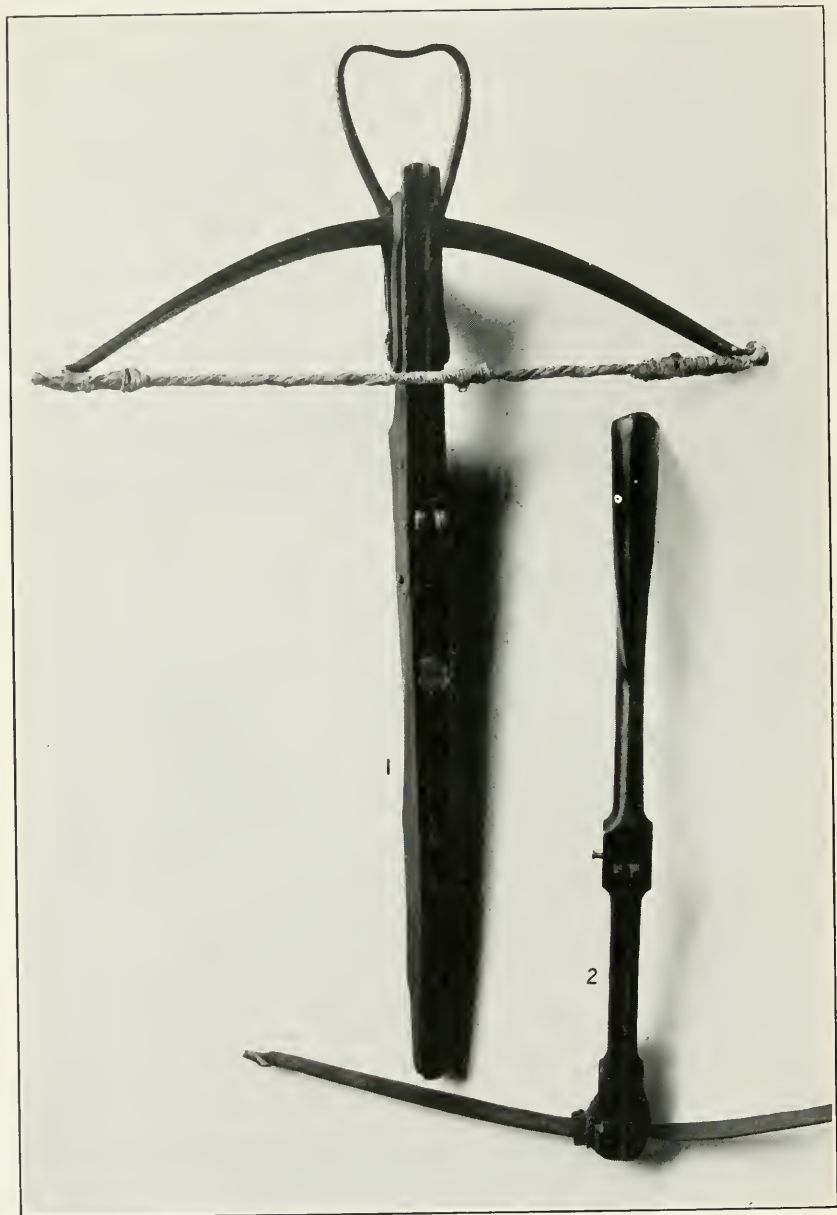
1, MEDIEVAL STIRRUP CROSSBOW, GERMANY; 2, MODERN SPORTING CROSSBOW.
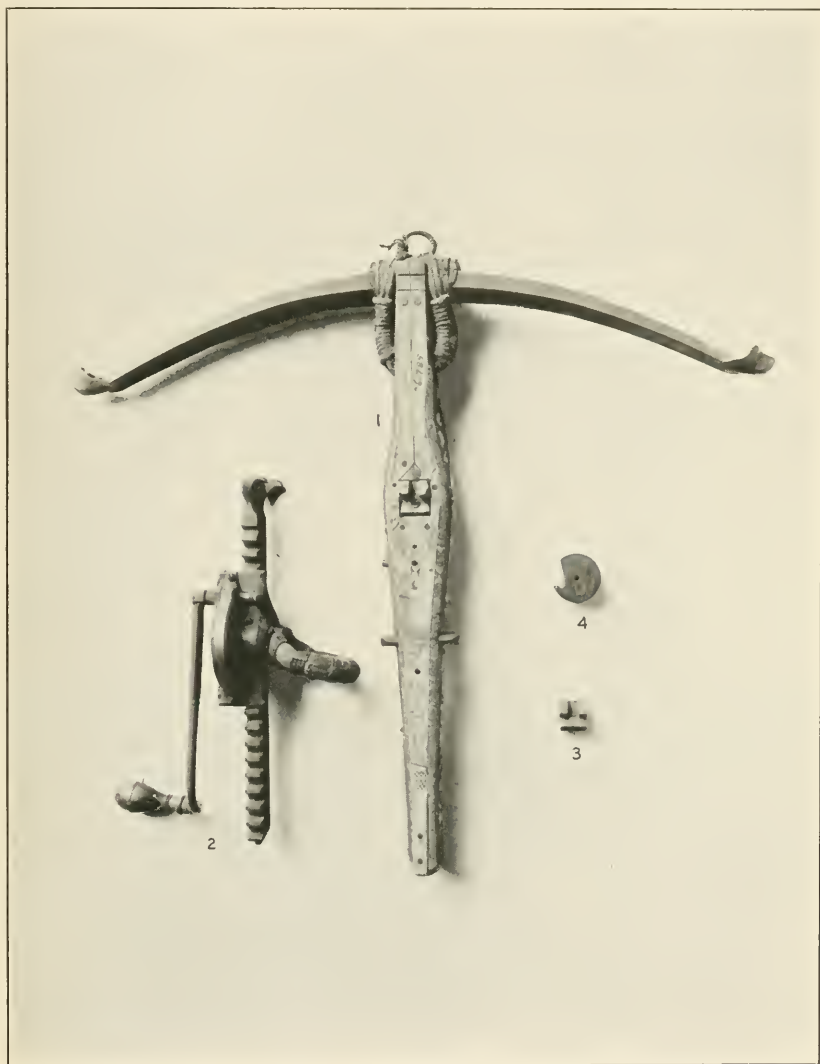
1, SIXTEENTH CENTURY SPORTING CROSSBOW, GERMANY; 2, CRANEQUIN FOR SPANNING THE SPORTING CROSSBOW, GERMANY; 3, BONE STRING-CATCH FROM PL. 4, FIG. 1; 4, WOOD STRING-CATCH FROM PL. 4, FIG. 2.
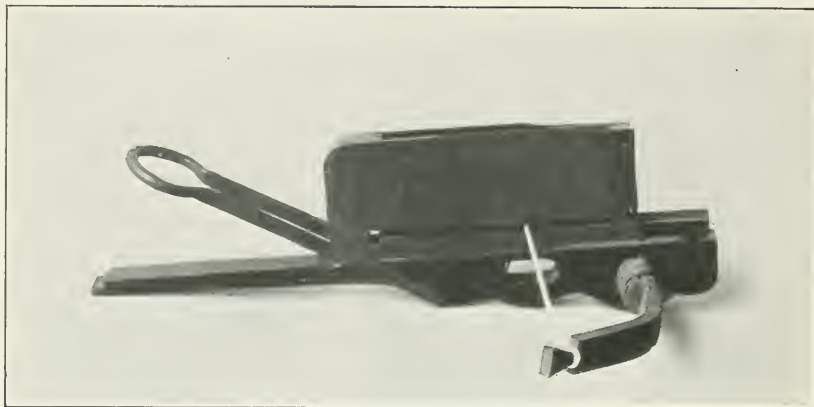
1, Repeating Crossbow at Rest, China.
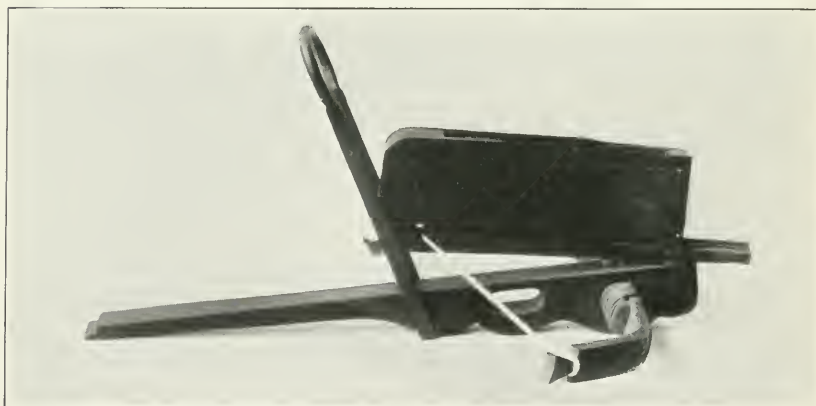
2, Repeating Crossbow Being Drawn, China.

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