SIXTH ANNUAL REPORT

OF THE

UNITED STATES GEOLOGICAL SURVEY

TO THE

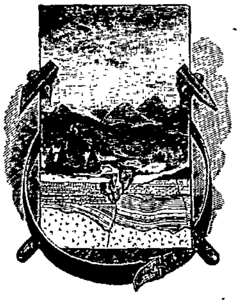
SECRETARY OF THE INTERIOR

1884-'85

BY

J. W. POWELL

DIRECTOR



WASHINGTON
GOVERNMENT PRINTING OFFICE
1885

REPORT

OF THE

DIRECTOR

OF THE

UNITED STATES GEOLOGICAL SURVEY.

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., July 31, 1885.

SIR: I have the honor to transmit herewith my report of the operations of the Geological Survey for the fiscal year ending June 30, 1885.

Please accept my thanks for the earnest support you have given to the work under my charge.

I am, with great respect, your obedient servant,

J. W. Powell

Director.

Hon. L. Q. C. LAMAR,
Secretary of the Interior.

SIXTH ANNUAL REPORT

OF THE

UNITED STATES GEOLOGICAL SURVEY.

By J. W. POWELL, *Director.*

TOPOGRAPHY.

During the fiscal year just closed fair progress has been made in the topographic survey of the United States. An area of 57,508 square miles has been surveyed and the maps thereof made ready for the engraver. The average cost of the work has been about three dollars per square mile. The following table shows the distribution of this work and the several scales upon which it has been executed:

Table of areas surveyed by the United States Geological Survey.[1]

Area.	Scale of publication.	Area (square miles).
Massachusetts	1: 62500	1,250
New Jersey	1: 62500	1,268
Appalachian region	1: 125000	17,640
Missouri-Kansas	1: 125000	13,600
Texas	1: 125000	4,000
Plateau region	1: 250000	15,000
Yellowstone Park	1: 125000	1,000
Northern California	1: 250000	3,750
Total		57,508

[1] A map, Plate I, exhibiting the areas surveyed, as tabulated above, in their relation to previous surveys, will be found in the pocket at the end of this volume.

During the past four years the Director has given special attention to methods of topographic surveying and cartographic systems, and a plan has at last been developed which seems to meet all requirements and to be reasonably economic. In the establishment of this plan the following considerations have had chief control:

1. The area of the United States is very great, being about three million square miles, exclusive of Alaska, and no nation has yet undertaken to execute a work of this character over a region of such magnitude. It has therefore been deemed of prime importance that the survey should be conducted with the utmost regard to economy.

2. The present purpose for which the map is constructed is the representation of the areal geology of the country, and the map should be constructed on such scales and represent such topographic features as are of prime importance in geologic representation; but while the immediate purpose of the map must be thus considered, it should be remembered that it may be made useful for many other important purposes in showing the geographic distribution of phenomena. Once constructed and engraved, the plates may serve for new editions from time to time, to be used for a great variety of purposes: in the study of drainage systems; in the study of the regimen of rivers; in the study of the great subject of irrigation; in the study of the distribution of forests; in the study of the distribution of artesian waters; in the study of catchment areas for the supply of water to cities; in the study of the drainage of swamps and overflowed lands; in the study of soils and the classification of lands for agricultural purposes; and in the laying out of highways, railroads, and canals. The maps will also be of prime importance for strategic and administrative purposes in the event of war. The uses for topographic maps when once constructed are very many, but there is no demand more exacting than that made by the geologist, and if properly made to meet his wants they will subserve all the purposes of the civil engineer, the agriculturist, the military engineer, and the naturalist; and it is believed that a topographic survey has been inaugurated which will meet all practical wants.

3. The need for a topographic map is perennial, and the map once constructed should be enduring, that the expense of frequent resurveys may be avoided; and this important condition has been carefully weighed.

4. The cost of the survey is paid from the National Treasury; it is therefore made at the expense of the people of the United States, and should meet the wants of the greatest number of persons; and the map should be so simple that it can be used by all people of intelligence.

The organization executing this work, as at present established, is as follows: First, an astronomic and computing division, the officers of which are engaged in determining the geographic coördinates of certain primary points. Second, a triangulation corps, engaged in extending a system of triangulation over various portions of the country from measured base lines. Third, a topographic corps, organized into twenty-seven parties, scattered over various portions of the United States.

The geographic basis of this map is a trigonometric survey, by which datum points are established throughout the country: that is, base lines are measured and a triangulation is extended therefrom. This trigonometric work is executed on a scale only sufficiently refined for map making purposes and will not be directly useful for geodetic purposes in determining the figure of the earth. The hypsometric work is based upon the railroad levels of the country. Throughout the greater part of the country there is a system of railroad lines, constituting a network. The levels or profiles of these roads have been established with reasonable accuracy, and as they cross one another at a multiplicity of points, a system of checks is afforded, so that the railroad surface of the country can be determined therefrom with all the accuracy necessary for the most refined and elaborate topographic maps. From such a hypsometric basis, the reliefs for the whole country are determined, by running lines of levels, by trigonometric construction, and in mountainous regions by barometric observation.

The primary triangulation having been made, the topography is executed by a variety of methods, adapted to the peculiar conditions found in various portions of the country. To a large extent the plane table is used. In the hands of the topographers of the Geological Survey the plane table is not simply a portable drafting table for the field: it is practically an instrument of triangulation, and all minor positions of the details of topography are determined through its use by trigonometric construction.

The plan for the map contemplates map sheets of three different scales, suited to the requirements of the various sections of the country, namely, 1:62500, 1:125000, and 1:250000. The first is approximately one mile to the inch, the second two miles to the inch, and the third four miles to the inch. The considerations governing the scale are, first, present or prospective density of settlement; second, economic importance; third, complexity of geologic phenomena; fourth, degree of detail in topographic features.

The map is constructed in contours, with vertical intervals of 10, 20, 50, 100, and 200 feet, varying with the scale of the map and the magnitude of relief features. The scale best adapted to each portion of the country has not yet been decided for the entire area of the United States; such decision can be reached only as the work progresses from region to region.

The map is to be engraved in sheets, of which the unit is to be the square degree, *i. e.*, one degree of latitude and one of longitude. On the four-mile scale each square degree forms one sheet; on the two-mile scale each square degree forms four sheets; while on the one-mile scale each square degree forms sixteen sheets. Four-mile sheets are designated by the numbers indicating the latitude and longitude of the southeast corner of the area represented. Thus, "40-100" designates the sheet which covers the degree immediately north of latitude 40 and west of longitude 100. The two-mile sheets are designated in the same way, with the addition of the further description "SE. $\frac{1}{4}$," "NE. $\frac{1}{4}$," "SW. $\frac{1}{4}$," "NW. $\frac{1}{4}$," as the case may be. In like manner the one-mile sheets are designated by the numbers representing the latitude and longitude of the degree,

LETTERING
FOR THE
TOPOGRAPHIC MAPS OF THE U.S. GEOLOGICAL SURVEY

CIVIL DIVISIONS

States Counties Townships Capitals and Principal Cities	MAINE	1
	MAINE	2
	MAINE	3
	MAINE	4
	MAINE	5
	MAINE	6
Towns and Villages	Rockville	7
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	BALTIMORE AND OHIO RAILROAD	12
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HYDROGRAPHY

Lakes Rivers and Bays	*LAKE ERIE*	14
	LAKE ERIE	15
	LAKE ERIE	16
	LAKE ERIE	17
	LAKE ERIE	18
	LAKE ERIE	19
	LAKE ERIE	20
Creeks Brooks Springs small Lakes Ponds Marshes and Glaciers	*Salt Creek*	21
	Salt Creek	22
	Salt Creek	23
	Salt Creek	24

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Mountains Plateaus Lines of Cliffs Valleys and Cañons	UINTA MOUNTAINS	25
	UINTA MOUNTAINS	26
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	UINTA MOUNTAINS	29
	UINTA MOUNTAINS	30
Peaks small Valleys and Cañons	Pikes Peak	31
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	Pikes Peak	33
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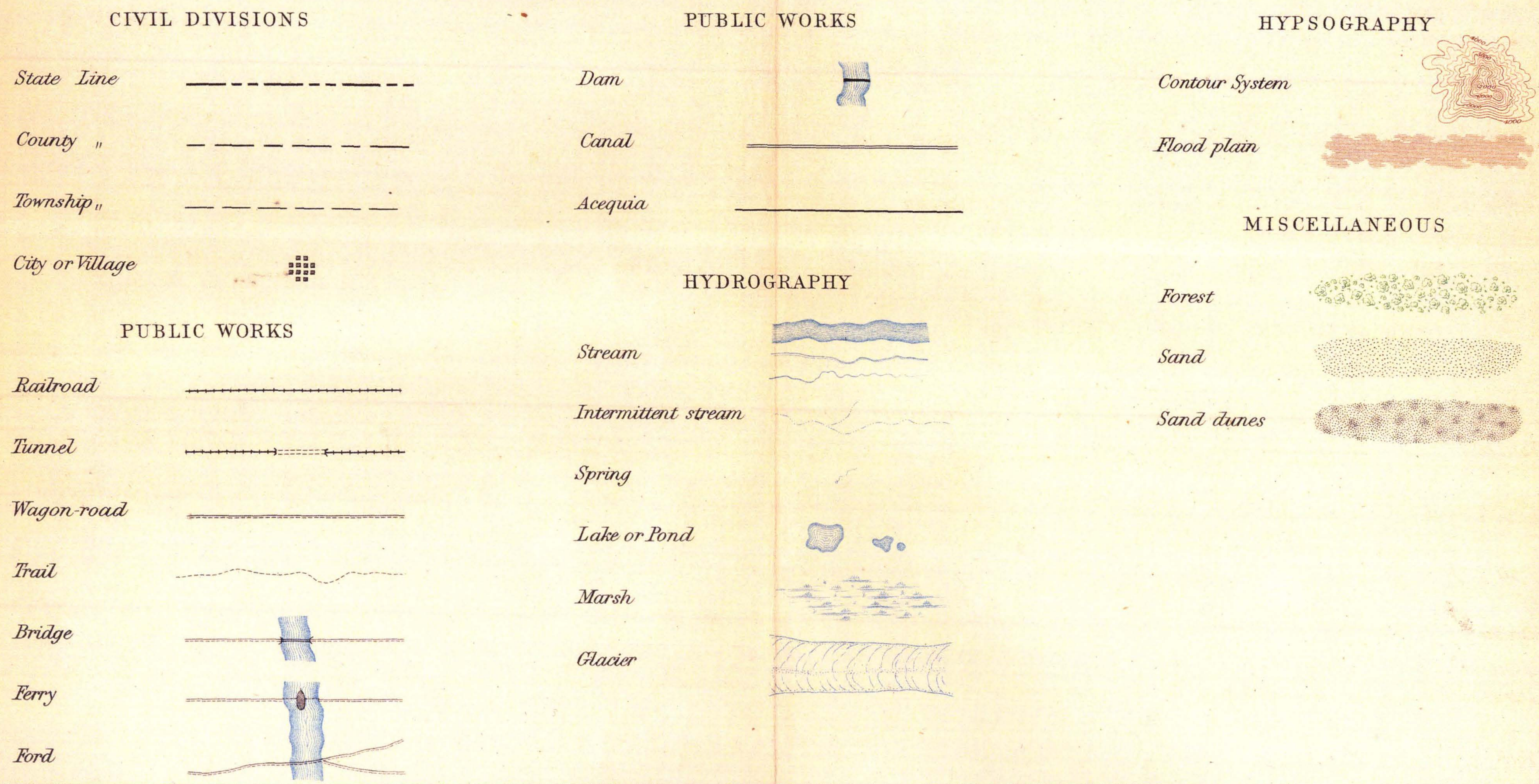
Julius Bien & Co. Lith.

CONVENTIONAL SIGNS
FOR THE
TOPOGRAPHIC MAPS OF THE U.S. GEOLOGICAL SURVEY



Julius Bien & Co. Lith.

with the addition of the proper fractional designations, such as "SE. $\frac{1}{4}$ of the SE. $\frac{1}{4}$," etc.

The sheets are to be engraved on copper, three plates being required for each. On one is to be engraved the hydrography; on the second, the hypsography, represented by grade curves; and on the third, the projection lines, lettering, and public culture. Private culture is not represented on the map. The hydrography will be printed in blue, the hypsography in brown, and the lettering and culture in black. Plates II and III exhibit the system of lettering and conventional signs adopted by the Survey.

PALEONTOLOGY.

Before giving the outline of the plan for the general geologic survey, it will be better to explain the accessory plans and organizations. There are in the Survey, as at present organized, the following paleontologic laboratories:

1. A laboratory of vertebrate paleontology for formations other than the Quaternary. In connection with this laboratory there is a corps of paleontologists. Professor O. C. Marsh is in charge.

2. There is a laboratory of invertebrate paleontology of Quaternary age, with a corps of paleontologists; Mr. Wm. H. Dall being in charge.

3. There is a laboratory of invertebrate paleontology of Cenozoic and Mesozoic age, with a corps of paleontologists. Dr. C. A. White is in charge.

4. There is a laboratory of invertebrate paleontology of Paleozoic age, with a corps of paleontologists. Mr. C. D. Walcott is in charge.

5. There is a laboratory of fossil botany, with a corps of paleobotanists; Mr. Lester F. Ward being in charge.

The paleontologists and paleobotanists connected with the laboratories above described study and discuss in reports the fossils collected by the general geologists in the field. They also supplement the work of the field geologists by making special collections in important districts and at critical horizons, but the paleontologists are not held responsible for areal and structural geology on the one hand and the geologists are not held responsible for paleontology on the other hand. In addition to the large number of paleontologists on the regular work of the Geological Survey, as above described, several paleontologists are engaged from time to time to make special studies.

CHEMISTRY.

There is a chemic laboratory attached to the Survey, with a large corps of chemists engaged in a great variety of researches relating to the constitution of waters, minerals, ores, and rocks. A part of the work of this corps is to study the methods of metamorphism and the paragenesis of minerals, and in this connection the chemists do work in the field; but to a large extent they are occupied with the study of the materials collected by the field geologists. Professor F. W. Clarke is in charge of this department.

PHYSICAL RESEARCHES.

There is a physical laboratory in the Survey, with a small corps of men engaged in certain physical researches of prime importance to geologic philosophy. These researches are experimental, and relate to the effect of temperatures, pressures, etc., on rocks. This laboratory is under the charge of the Chief Chemist.

LITHOLOGY.

There is a lithologic laboratory in the Survey, with a large corps of lithologists engaged in the microscopic study of rocks. These lithologists are field geologists, who examine the collections made by themselves.

STATISTICS.

There is in the Survey a division of mining statistics, with a large corps of men engaged in statistic work, the results of which are published in an annual report entitled "Mineral Resources." Mr. Albert Williams, jr., is the Chief Statistician of the Survey.

ILLUSTRATIONS.

There is in the Survey a division organized for the purpose of preparing illustrations for paleontologic and geologic reports. Mr. W. H. Holmes is in charge of this division. Illustrations will not hereafter be used for embellishment, but will be strictly confined to the illustration of the text and the presentation of such facts as can be best exhibited by figures and diagrams. All illustrations will, as far as possible, be prepared by relief methods, such as wood engraving, photo-engraving, etc. As large numbers of the reports of the Survey are published, this plan is demanded for economic reasons; but there is another consideration believed to be of still greater importance: illustrations made on stone cannot be used after the first edition, as they deteriorate somewhat by time, and it is customary to use the same lithographic stone for various purposes from time to time. The illustrations made for the reports of the Survey, if on relief-plates that can be cheaply electrotyped, can be used again when needed. This is especially desirable in paleontology, where previously published figures can be introduced for comparative purposes There are two methods of studying the extinct life of the globe: fossils are indices of geological formations, and must be grouped by formations to subserve the purpose of geologists; fossils also have their biologic relations, and should be studied and arranged in biologic groups. Under the plan adopted by the Survey, the illustrations can be used over and over again for such purposes when needed, as reproduction can be made at the small cost of electrotyping. These same illustrations can be used by the public at large in scientific periodicals, text books, etc. All the illustrations made by the Geological Survey are held for the public to be used in this manner.

LIBRARY.

The library of the Survey now contains 15,000 books and about 10,000 pamphlets, and is rapidly growing by means of exchanges. It is found necessary to purchase but few books.

The librarian, Mr. C. C. Darwin, has a corps of assistants engaged in bibliographic work. It is proposed to prepare a catalogue of American and foreign publications upon American geology, which is to be a general authors' catalogue. In addition to this, it is proposed to publish bibliographies proper of special subjects constituting integral parts of the science of geology

PUBLICATIONS.

The publications of the Survey are in three series: Annual Reports, Bulletins, and Monographs. The Annual Report constitutes a part of the Report of the Secretary of the Interior for each year, but is a distinct volume. This contains a brief summary of the purposes, plans, and operations of the Survey, prepared by the Director, and short administrative reports from the chiefs of divisions, the whole followed by scientific papers. These papers are selected as being those of most general interest, the object being to make the Annual Report a somewhat popular account of the doings of the Survey, that it may be widely read by the intelligent people of the country. Of this 5,650 copies are published as Volume III of the Secretary's Annual Report, and are distributed by the Secretary of the Interior, Senators, and Members of the House of Representatives; and an extra edition is annually ordered of 15,000 copies, distributed by the Survey and members of the Senate and House of Representatives. Four Annual Reports have been published; the fifth is now in type and ready to be put to press.

The Bulletins of the Survey are short papers, and through them somewhat speedy publication is attained. Each bulletin is devoted to some specific topic, in order that the material ultimately published in the bulletins may be classified in any manner desired by scientific men. Thirteen bulletins have been published, nine are ready to be put to press, and two are in the hands of the printer in manuscript. The bulletins already published vary in size from 5 to 325 pages each. They are sold at the cost of press-work and paper, and vary in price from 5 to 20 cents each. Four thousand nine hundred copies of each bulletin are published: 1,900 are distributed by Congress; 3,000 are held for sale and exchange by the Geological Survey.

The Monographs of the Survey are quarto volumes. By this method of publication the more important and elaborate papers are given to the public. Seven monographs, with two atlases, have been issued; five monographs, with two atlases, are in press. One thousand nine hundred copies of each monograph are distributed by Congress; 3,000 are held for sale and exchange by the Survey at the cost of press-work, paper, and binding. They vary in price from $1.05 to $11.

The chiefs of divisions supervise the publications that originate in their several corps. The general editorial supervision is exercised by the chief clerk of the Survey, Mr. James C. Pilling

GENERAL GEOLOGY.

In organizing the general geologic work, it became necessary, first, to consider what had already been done in various portions of the United States; and for this purpose the compilation of a general geologic map of the United States was begun, together with a thesaurus of American formations. In addition to this the bibliographic work previously described was initiated, so that the literature relating to American geology should be readily accessible to the workers in the Survey. At this point it became necessary to consider the best methods of apportioning the work; that is, the best methods of dividing the geologic work into parts to be assigned to the different corps of observers. A strictly geographic apportionment was not deemed wise, from the fact that an unscientific division of labor would result and the same classes of problems would to a large extent be relegated to the several corps operating in field and in the laboratory. It was thought best to divide the work, as far as possible, by subject-matter rather than by territorial areas; yet to some extent the two methods of division coincide. There are in the Survey at present:

First, a division of glacial geology, and Prof. T. C. Chamberlin, formerly State geologist of Wisconsin, is at its head, with a strong corps of assistants. There is an important field for which definite provision has not yet been made, namely, the study of the loess that constitutes the bluff formations of the Mississippi River and its tributaries. But as this loess proves to be intimately associated with the glacial formations of the same region, it is probable that it will eventually be relegated to the glacial division. Perhaps the division may eventually grow to such an extent that its field of operations will include the whole of Quaternary geology.

Second, a division of volcanic geology is organized, and Capt. Clarence E. Dutton, of the Ordnance Corps of the Army, is placed in charge, also with a strong corps of assistants.

Third and fourth, two divisions have been organized to prosecute work on the Archean rocks, embracing within their field not only all rocks of Archean age, but all metamorphic crystalline schists, of whatever age they may be found. The first division has for its chief, Prof. Raphael Pumpelly, assisted by a corps of geologists, and the field of his work is the crystalline schists of the Appalachian region, or eastern portion of the United States, extending from northern New England to Georgia. He will also include in his studies certain Paleozoic formations which are immediately connected with the crystalline schists and involved in their orographic structure. The second division for the study of this class of rocks is in charge of Prof. Roland D. Irving, with a corps of geologists, and his field of operation is in the Lake Superior region. It is not proposed at present to undertake the study of the crystalline schists of the Rocky Mountain region.

Fifth, another division has been organized for the study of the areal, structural, and historical geology of the Appalachian region, extending from the Atlantic westward to the zone which separates the mountain region from the great valley of the Mississippi. Mr. G. K. Gilbert has charge of this work, and has a large corps of assistants.

Sixth, it seemed desirable, partly for scientific reasons and partly for administrative reasons, that a thorough topographic and geologic survey should be made of the Yellowstone Park, and Mr. Arnold Hague is in charge of the work, with a corps of assistants. When it is completed, his field will be expanded so as to include a large part of the Rocky Mountain region, but the extent of the field is not yet determined.

It will thus be seen that the general geologic work relating to those areas where the terranes are composed of fossiliferous formations is very imperfectly and incompletely organized. The reason for this is two fold: first, the work cannot be performed very successfully until the maps are made; second, the Geological Survey is necessarily diverting much of its force to the construction of maps, and cannot with present appropriations expand the geologic corps so as to extend systematic work in the field over the entire country.

ECONOMIC GEOLOGY.

Under the organic law of the Geological Survey investigations in economic geology are restricted to those States and Territories in which there are public lands; the extension of the work into the eastern portion of the United States included only that part relating to general geology. Two mining divisions are organized. One, in charge of Mr. George F. Becker, with headquarters at San Francisco, California, is at the present time engaged in the study of the quicksilver districts of California. The other, under charge of Mr. S. F. Emmons, with headquarters at Denver, Colorado, is engaged in studying various mining districts in that State, including silver, gold, iron, and coal areas. Each division has a corps of assistants. The lignite coals of the upper Missouri, also, have been under investigation by Mr. Bailey Willis, with a corps of assistants.

APPOINTMENTS.

Three classes of appointments are made on the Survey. The statute provides that "the scientific employés of the Geological Survey shall be selected by the Director, subject to the approval of the Secretary of the Interior, exclusively for their qualifications as professional experts." The provisions of this statute apply to all those cases where scientific men are employed who have established a reputation, and in asking for their appointment the Director specifically states his reasons, setting forth the work in which the person is to be employed, together with his qualifications, especially enumerating and characterizing his published works. On such recommendations appointments are invariably made. Young men who have not established a reputation in scientific research are selected through the agency of the Civil Service Commission on special examination, the papers for which are prepared in the Geological Survey. About one-half of the employés, however, are temporary, being engaged for services lasting for a few days or a few months only, largely in the field, and coming under two classes: skilled laborers and common laborers. Such persons are employed by the Director or by the heads of divisions, and are discharged from the service when no longer needed. It will be seen that the Director is responsible for the selection of the employés, directly for those whom he recommends for appointment and indirectly for those selected by the Civil Service Commission whom he permanently retains in the work. If, then, improper persons are employed, it is wholly the Director's fault.

GOVERNMENT AND STATE SURVEYS.

The United States Geological Survey is on friendly relations with the various State Surveys. The State of Massachusetts still co-operates with the United States in the survey of that Commonwealth, as fully set forth in the last Annual Report. Between the Government Survey and the State Survey of New York, there is direct co-operation. The State Survey of Pennsylvania has rendered valuable assistance to the Government Survey, and negotiations have been entered into for closer relations and more thorough co-operation. The State Surveys of North Carolina, Kentucky, and Alabama are also co-operating with the Government Survey, and the Director of the Government Survey is doing all within his power to revive State Surveys. The field for geologic research in the United States is of great magnitude, and the best results can be accomplished only by the labors of many scientific men engaged for a long term of years. For this reason it is believed that surveys should be established in all of the States and Territories. There is work enough for all, and the establishment of local surveys would greatly assist the general work prosecuted under the auspices of the Government and prevent it from falling into perfunctory channels. Its vigor and health will doubtless be promoted by all thorough local research.

It may be of interest to scientific men to know that the Director finds that in presenting the general results, interests, and needs of the Survey to Congress and to Committees of Congress, a thorough appreciation of the value of scientific research is shown by the statesmen of the country. Questions relating to immediately economic values are asked, as they should be; but questions relating to sound administration, wise methods of investigation, and important scientific results are vigorously urged, and the principle is recognized that all sound scientific research conduces to the welfare of the people, not only by increasing knowledge, but ultimately by affecting all the industries of the people.

OFFICE OF THE SURVEY.

Since the last Annual Report was submitted the Survey offices have been moved into the new building on F street rented by the Government for this purpose. The building is commodious and well arranged, and the office work is thereby accomplished with greater promptness and economy. The laboratories of the Survey remain in the National Museum, and some inconvenience results from the fact that the general offices are severed from the laboratories.

FINANCIAL STATEMENT.

Amounts appropriated by Congress for the work of the United States Geological Survey for the fiscal year ending June 30, 1885.

		Geological Survey.	Salaries, office of Geological Survey.	Total appropriation.
Amounts appropriated		$453,700 00	$35,840 00	$489,040 00
Amounts expended, classified as follows:				
Expenses.				
A.—Services	$286,394 18			
B.—Traveling expenses	32,290 25			
C.—Transportation of property	8,200 76			
D.—Field subsistence	14,764 64			
E.—Field supplies and expenses	21,222 04			
F.—Field material	20,519 60			
G.—Instruments	11,772 88			
H.—Laboratory material	7,767 86			
I.—Photographic material	6,194 65			
K.—Books and maps	10,274 04			
L.—Stationery and drawing material	4,229 67			
M.—Illustrations for reports	3,172 60			
N.—Office rents	1,929 62			
O.—Office furniture	10,930 27			
P.—Office supplies and repairs	6,104 38			
Q.—Storage	330 80			
R.—Correspondence	1,147 59			
S.—Bonded railroad accounts: Freight, $296.54; transportation of assistants, $2,279.88	2,576 42	449,822 25		
Salaries.				
A.—Salaries			35,174 50	484,996 75
Balance unexpended		3,877 75	165 50	4,043 25
Probable amount required to meet outstanding liabilities		3,877 75		3,877 75

REPORTS OF OPERATIONS.

The operations of the Survey for the fiscal year are fully set forth in the accompanying administrative reports made by the several heads of divisions.

In conclusion, it is the pleasure of the Director to acknowledge with grateful thanks the hearty co-operation of the various members of the Survey in the work under his charge. By their genius, learning, and efficiency all measure of success attained has been achieved.

The Survey is deeply indebted to the honorable Secretary of the Smithsonian Institution, Prof. Spencer F. Baird, for providing laboratory rooms for its use in the National Museum and facilities for the installment of its great collections.

Free transportation has been extended to the members of the Survey by many of the railroads of the United States, thus greatly increasing the ability of the Survey to extend its scientific researches. The thanks of the Director are hereby extended to the officers of these roads.

The Survey is deeply indebted to the Public Printer, the Hon. S. P. Rounds, for the aid which he has given it in systematizing the illustrations for its reports and in the adoption of economic methods of reproduction. The scientific reports are very complex and their mechanical reproduction is a task of difficulty and magnitude. To this task the officers of the Government Printing Office have devoted great pains, and very important improvements in the reports of the Survey have resulted therefrom.

DEPARTMENT OF THE INTERIOR, UNITED STATES GEOLOGICAL SURVEY.

ADMINISTRATIVE REPORTS

OF

CHIEFS OF DIVISIONS

AND

HEADS OF INDEPENDENT PARTIES

ACCOMPANYING THE ANNUAL REPORT OF THE

DIRECTOR OF THE U. S. GEOLOGICAL SURVEY

FOR THE

FISCAL YEAR ENDING JUNE 30, 1885.

ADMINISTRATIVE REPORTS.

REPORT OF MR. HENRY GANNETT.

UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF GEOGRAPHY,
Washington, June 30, 1885.

SIR: During the year topographic work has been carried on in all the fields occupied during the previous year, including Massachusetts, the southern Appalachian region, the plateau region of the southwest, the Yellowstone Park, and northern California. In Massachusetts and in the Southern Appalachian region the scale of the maps has been enlarged with a view to the representation of the topography in greater detail and with correspondingly more accuracy than former plans contemplated. In addition to the areas above enumerated, work has been commenced in Missouri, in Kansas, and in Texas, and the field of operations in the southwest plateau region has been extended into southeastern Utah and southern Nevada; while, furthermore, work has been carried on by this organization in New Jersey, as a portion of a plan of co-operation with the Geological Survey of that State.

The total area surveyed during the season was 57,508 square miles, distributed as follows among the several areas of work projected:

Area.	Scale of publication.	Area, square miles.
Massachusetts	1 : 62500	1, 250
New Jersey	1 : 62500	1, 268
Appalachian region	1 : 125000	17, 640
Missouri-Kansas	1 : 125000	13, 600
Texas	1 : 125000	4, 000
Plateau region	1 : 250000	15, 000
Yellowstone Park	1 : 125000	1, 000
Northern California	1 : 250000	3, 750
		57, 508

The average cost of all the work done has been about $3 per square mile.

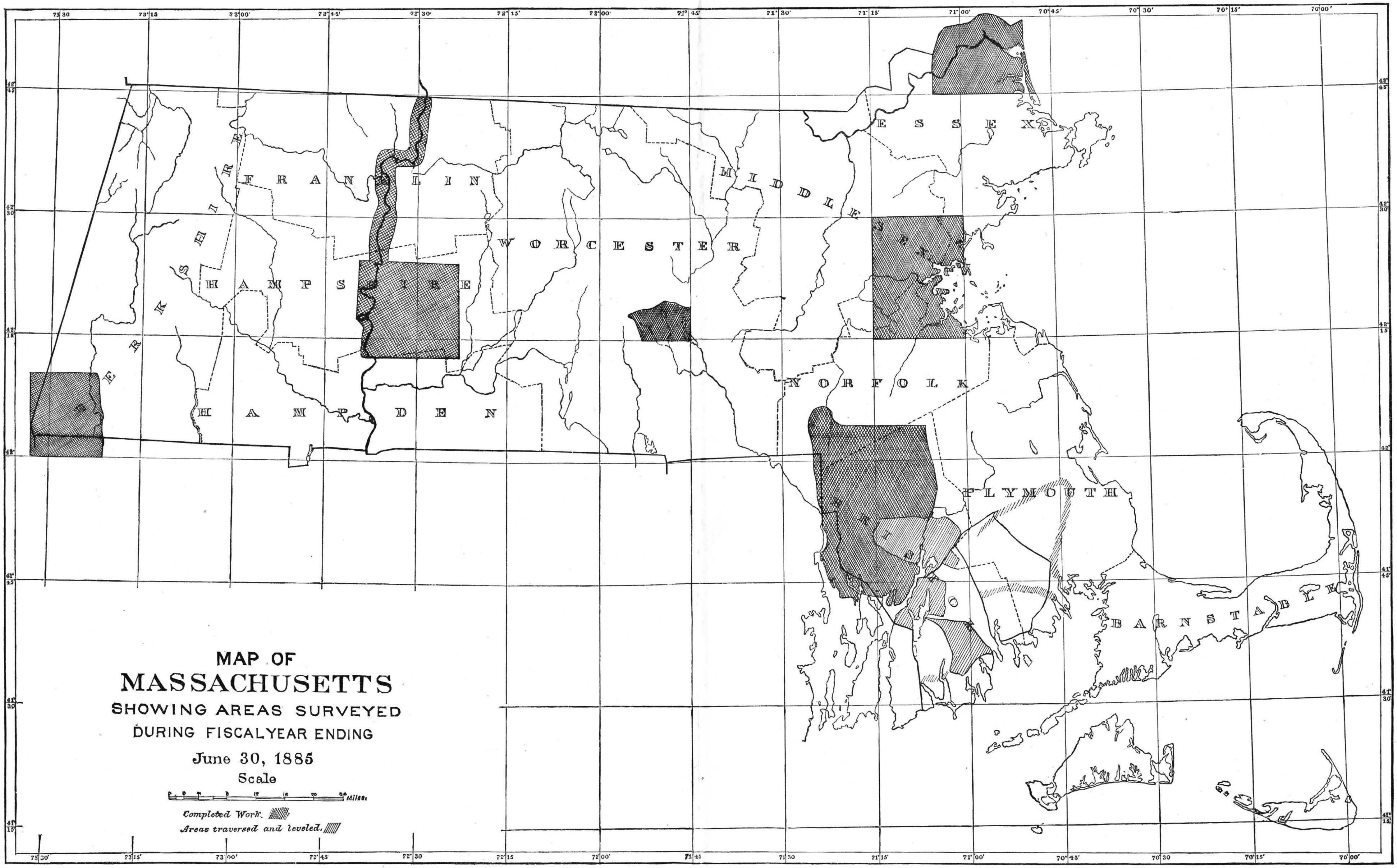
NEW ENGLAND DIVISION.

During the spring of 1884 the legislature of Massachusetts passed an act appropriating $40,000, which amount was estimated to be one-half of that required for making a map of the State in sufficient detail to be published on a scale of 1 mile to an inch. This was done upon the condition that this organization should pay the other half. The interests of the State were placed in the hands of a commission consisting of General Francis A. Walker, president of the Massachusetts Institute of Technology, Prof. H. L. Whiting, of the United States Coast and Geodetic Survey. and Prof. N. S. Shaler, of Harvard University. Under a proposition made by the Director and accepted by the commission, work was commenced by this Survey and carried forward by it for two months, the results to be accepted or rejected by the commission. In accordance with the result of their examinations, in October the work was accepted by the commission, and it has been since carried on at the joint expense of the State and of this organization.

Before the close of the last fiscal year Professor Walling had been placed in the field in the southwestern part of Massachusetts. He commenced work in the town of Mount Washington, and was engaged until August in extending a minute triangulation in that and the neighboring towns and adjoining portions of New York and Connecticut. In August there were detailed to his party, Mr. E. W. F. Natter, as plane tabler, Mr. J. H. Jennings, assistant topographer, and one field assistant. By this party, work was carried on until the latter part of November, when field-work in this area was in the main given up and Messrs. Walling and Natter were ordered to Boston. Mr. Jennings remained in the field during the winter engaged in making traverse surveys and running level lines in the valley of the Housatonic.

Shortly after the return of Mr. Natter to Boston he was instructed to undertake, during the intervals of good weather in the winter, the survey of the country included in the atlas sheet comprising 15 minutes of longitude and 15 of latitude which embraces Boston and its immediate surroundings. This work has necessarily progressed slowly during the winter, owing to the large amount of severe weather, but during the spring it has gone on more rapidly, and is now nearly completed.

During the month of August three additional parties were directed to take the field in Massachusetts. One, under Mr. Anton Karl, comprising, besides himself, Mr. Frederick Roeser, Mr. R. H. McKee, and two field assistants, was directed to survey the country in the middle portion of the State east of the Connecticut River, its western line being that stream. Another party, under Mr. S. H. Bodfish, to whom were detailed Messrs. C. C. Bassett, R. H. Phillips, and two rodmen, undertook the survey of the northern portion of Bristol County, in the southeastern part of the State. The other party was in charge of Mr. J. D. Hoffmann, and to him were detailed Messrs. D. J. Howell, Felix Freyhold,


MAP OF
MASSACHUSETTS
SHOWING AREAS SURVEYED
DURING FISCAL YEAR ENDING
June 30, 1885
Scale
Miles
Completed Work.
Areas traversed and leveled.
ESSEX
MIDDLESEX
FRANKLIN
WORCESTER
BERKSHIRE
HAMPSHIRE
HAMPDEN
NORFOLK
PLYMOUTH
BRISTOL
BARNSTABLE

and two rodmen. To this party was assigned the northern portion of Essex County. These parties prosecuted field work continuously until the end of November. The areas surveyed by them are represented upon the accompanying sketch, Plate IV.

During the winter Messrs. Karl, Bodfish, and Hoffmann, with such of their assistants as were retained, have been in Washington engaged upon the work of finishing their maps, making transcripts of them for deposit with the State of Massachusetts and in compiling for future use the surveys of the United States Coast and Geodetic Survey on and near the coast. In addition to his share of this work Mr. Karl, with his assistant, has been occupied during May and June in plotting the Denver map, referred to in my last report.

Mr. Hoffmann was detailed early in April to other work.

On April 22 Mr. Bodfish was ordered to the field for the purpose of extending the area surveyed by him during the previous field season, and Messrs. C. C. Bassett, R. H. Phillips, Laurence Thompson, and six field assistants, including rodmen, were placed under his orders, forming a large and effective working party. By the middle of May he was well at work, and is making rapid progress.

Early in March work was commenced in Worcester County, by Mr. W. D. Johnson. As the season opened, three field assistants were detailed to him, and he is making good progress and doing excellent work.

An estimated area of 1,250 square miles has been surveyed during the year in the State of Massachusetts.

NEW JERSEY.

On July 16, 1884, the topographic work previously carried on by the Geological Survey of New Jersey was assumed by the United States Geological Survey. A brief sketch of the work done by the State prior to that date will be instructive in connection with a statement of its progress during the past fiscal year.

Work done by the State Geological Survey.—The topographical survey of New Jersey was begun under the direction of the board of managers of the Geological Survey of that State in 1876 and 1877 by the survey of the clay district of Middlesex County, from which the principal part of the fire and potter's clays of New Jersey are obtained. The field work was done by the late James K. Barton. This work covered about 70 square miles, was drawn on a scale of 3 inches to a mile, and was published with the State geological report upon that district in 1878. In the same year the topographical survey of the eastern part of the State, which includes Newark, Jersey City, and the thickly settled country adjoining, was begun. The field work was in charge of Mr. George W. Howell during that year and the one following, and 746 square miles were surveyed. The maps were drawn on a scale of 3 inches to a mile, and the work was then reduced to a scale of 1 inch to a mile, and was published by the State geological survey in 1882, under the title of

"Topographic Map of a Portion of Northern New Jersey." This map covered an area of 847 square miles.

The value of this map to the survey as well as to the economic interests of the State was so apparent that it was thought best to continue the survey over the whole of its area. The surveying parties were organized under the charge of Mr. C. C. Vermeule, and work was continued as rapidly as means would permit. A plan for mapping and publishing the whole area of the State was matured and adopted. The maps were drawn on a scale of 3 inches to a mile and were reduced for publication on a scale of 1 inch to a mile. The sheets, numbering 17, are 24 by 34 inches. The irregular form of the State rendered it difficult to arrange these sheets in regular order, and they were therefore placed so as to include geological areas, and instead of lying edge to edge they overlap to some extent. The accompanying key-map (Plate No. V) shows the locations and numbers of the several topographic maps. Maps Nos. 3, 4, and 7 were printed at the end of 1883; Nos. 2, 6, and 16 were printed at the end of 1884 and Nos. 1, 9, 13, and 17 are well advanced. Up to July 16, 1884, there had been surveyed 3,356 square miles out of the estimated area of the State, 7,576 square miles. By far the most rugged part of the State was included in the surveyed area. The accompanying sketch-map shows the area surveyed up to that time.

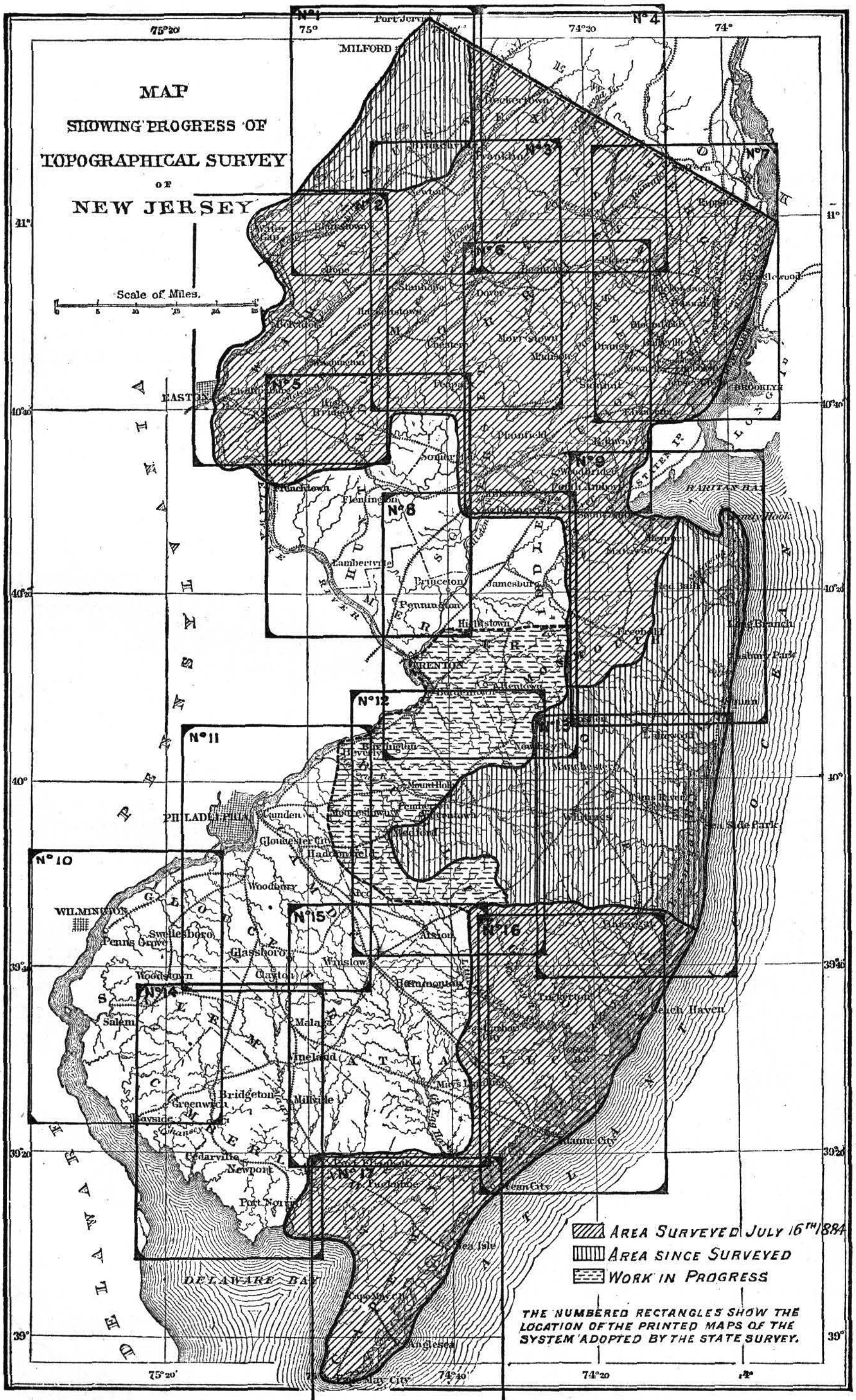
At the opening of the season of 1884 the parties were organized under Mr. Vermeule, as follows:

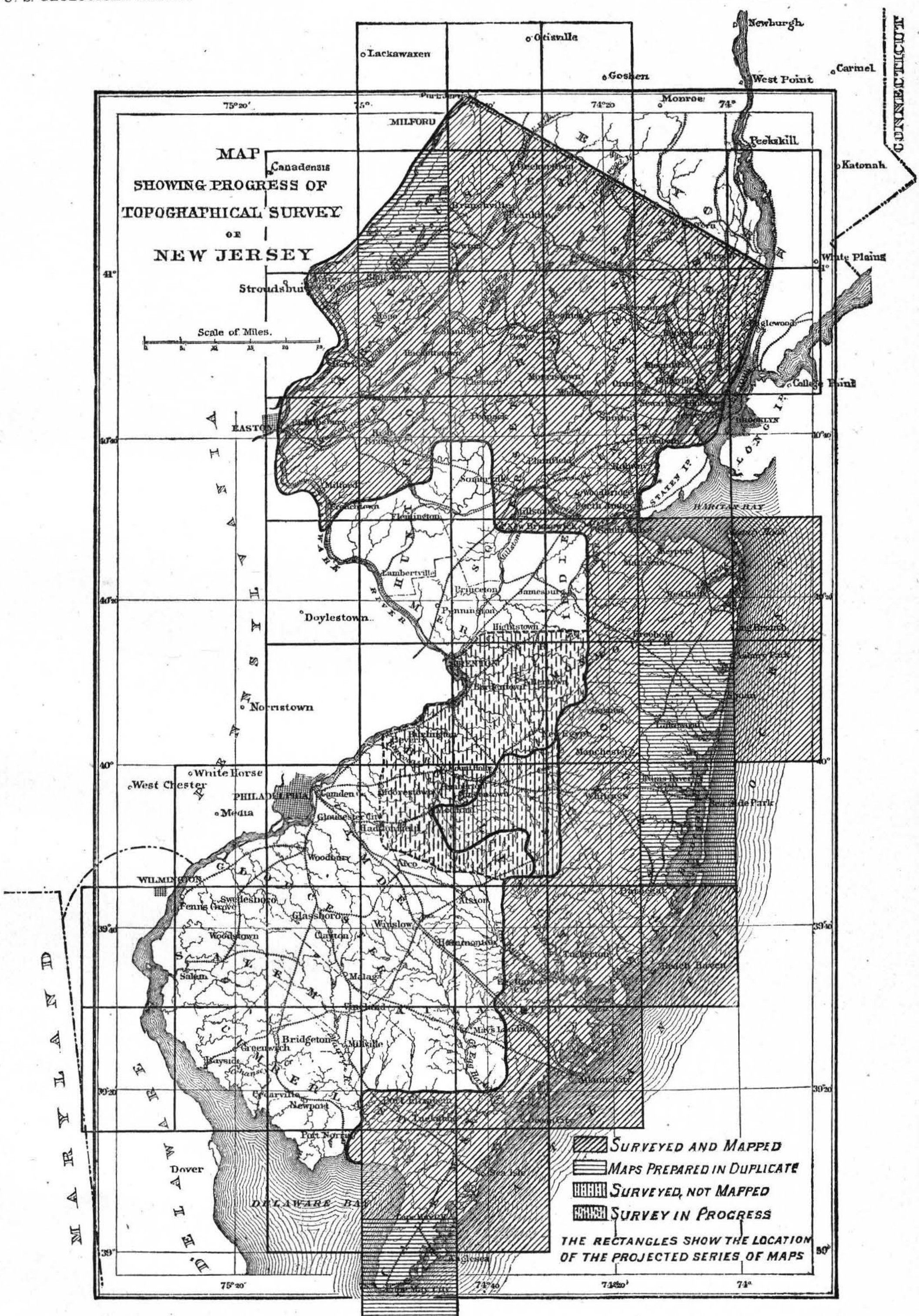
One leveling and contouring party under Mr. F. W. Bennett.
One leveling and contouring party under Mr. George Hill.
One leveling and contouring party under Mr. C. F. Sproul.
Three odometer recorders, in charge of Mr. P. D. Staats.

Work during the past fiscal year.—On the 16th of July the corps of assistants in the topographic survey of New Jersey was transferred into the service of the United States Geological Survey. Its office remained in the rooms of the geological survey of New Jersey at New Brunswick, and the instruments belonging to that survey were continued in use.

From July 16 to December 20, 1884 the parties were continued in the field and 1,082 square miles were surveyed. During the winter the several members of the corps were engaged in plotting the notes which had been taken, and full occupation was found in this up to the time for resuming field-work.

The mapping having been completed, on April 21 Mr. P. D. Staats, assisted by Mr. W. H. Luster, took the field and proceeded with the traversing of roads, etc. They have continued this work until the present date, having covered about 750 square miles. Messrs. F. W. Bennett and P. H. Bevier, assisted by Mr. J. G. Tait, proceeded to Sandy Hook on May 4 and made a thorough survey of that place with transit and stadium; and, on the 18th of the same month, Messrs. Bennett and


MAP
SHOWING PROGRESS OF
TOPOGRAPHICAL SURVEY
OF
NEW JERSEY
Scale of Miles.
AREA SURVEYED JULY 16TH 1884
AREA SINCE SURVEYED
WORK IN PROGRESS
THE NUMBERED RECTANGLES SHOW THE LOCATION OF THE PRINTED MAPS OF THE SYSTEM ADOPTED BY THE STATE SURVEY.
DELAWARE BAY
RARITAN BAY
PHILADELPHIA
TRENTON
EASTON
WILMINGTON
BROOKLYN
75°20'
75°
74°20
74°
41°
40°20'
40°
39°20'
39°


MAP
SHOWING PROGRESS OF
TOPOGRAPHICAL SURVEY
OF
NEW JERSEY
Scale of Miles.
SURVEYED AND MAPPED
MAPS PREPARED IN DUPLICATE
SURVEYED, NOT MAPPED
SURVEY IN PROGRESS
THE RECTANGLES SHOW THE LOCATION
OF THE PROJECTED SERIES OF MAPS
PHILADELPHIA
Trenton
Newburgh
West Point
Peekskill
Katonah
White Plains
Carmel
CONNECTICUT
Lackawaxen
Otisville
Goshen
Monroe
MILFORD
Canadensis
Stroudsburg
EASTON
Doylestown
Norristown
White Horse
West Chester
Media
WILMINGTON
Dover
MARYLAND
DELAWARE
DELAWARE BAY
RARITAN BAY
STATEN ID.
BROOKLYN
Camden
Princeton
Lambertville
Flemington
Somerville
Woodbury
Glassboro
Bridgeton
Millville
Salem
Woodstown
Swedesboro
Atlantic City
Barnegat
Beach Haven
Long Branch
Manchester
Toms River
Freehold
Sea Isle
Cape May City

W. F. Marvin began running primary lines of levels from Sandy Hook southward toward Camden. They have been engaged in this work to the present date, having run 150 miles of levels. Mr. George Hill, assisted by Mr. Marvin, and later by Mr. Tait, has been engaged in running primary lines of levels and in contouring since May 4, and Mr. P. H. Bevier, with Mr. George G. Earl as assistant, has been engaged in contouring since May 25. Since the opening of the season, about 180 square miles have been completely surveyed and much preliminary work has been done on an additional area of more than 500 square miles. Messrs. C. F. Sproul and F. Van Brakle have assisted in the office since the opening of the season for field work.

The present condition of the survey will be best understood by a reference to the accompanying key-map (Plate VI) of the State of New Jersey, on which are drawn the outlines of the several sheets, designed by the United States Geological Survey to cover the State. It will be seen that each of these sheets is one-quarter of a degree of latitude in its length and a quarter of a degree of longitude in its breadth. The shading shows the present extent of the surveys. In general terms, it may be said that 4,616 square miles have been surveyed, leaving 2,960 square miles unsurveyed.

The methods of work pursued give very satisfactory results, as shown by the various checks applied to them, and appear to be those best adapted to the smooth and wooded country in which they are carried on. The basis of the work is furnished by the United States Coast and Geodetic Survey, that organization having supplied the positions of 50 primary triangulation points and about 250 secondary and tertiary triangulation points, being an average of one in each 25 square miles. Upon these points the topographic surveys are adjusted so nearly that no appreciable error can be detected on the maps. In surveying, the distances are measured by the odometer and the bearings by the azimuth compass. For determining altitudes, the engineer's level is used, and the datum plane, to which all elevations are referred, is that of mean tide at Sandy Hook. Substantial, permanent, and carefully secured bench-marks from this datum plane are being set in all parts of the State, so that reference may be made to them by engineers and surveyors. These also become permanent records, to which reference may be had in future time in determining whether there is any change in the relative heights of the land and the sea.

APPALACHIAN DIVISION.

The necessity for a larger scale for the maps of the southern Appalachian region having become apparent, not only on account of the prospective development of that region but also because of the intricacy of its geologic phenomena, it was decided to publish the maps upon a scale of 1:125000, in contours 100 feet apart. While most of the work hitherto done in this region has been in sufficient detail for publication upon this scale, it was apparent that in certain regions some revision would be necessary.

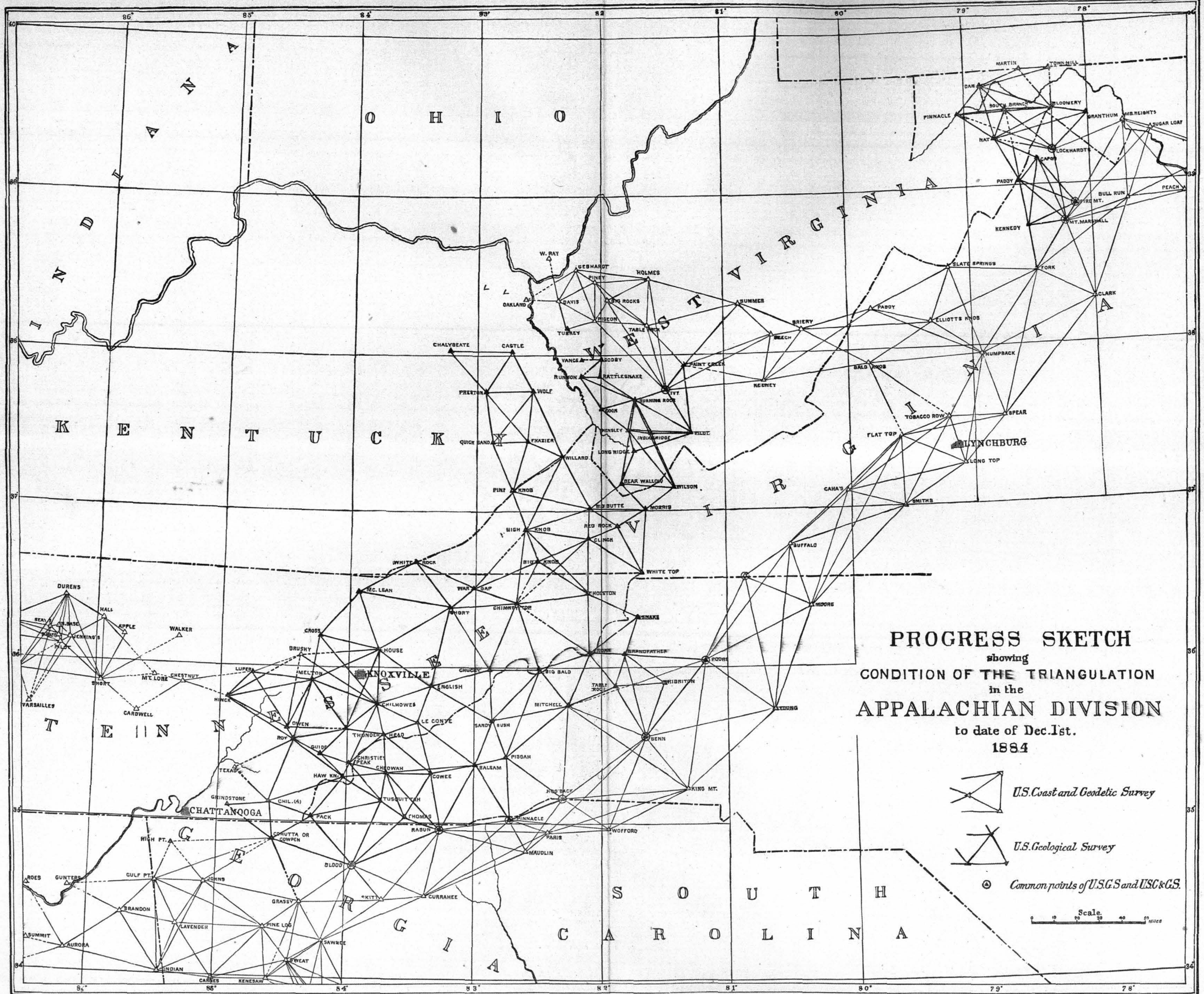
Mr. Gilbert Thompson, geographer, who had hitherto had charge of the California division, was transferred to the east and placed in charge of the Appalachian division. The latter was organized with one triangulation party, under Mr. S. S. Gannett, having Mr. J. W. Hays as assistant, and six topographic parties, respectively, under Messrs. W. T. Griswold, Morris Bien, W. A. Shumway, F. M. Pearson, C. M. Yeates, and Louis Nell, the party of the latter being a new organization.

Mr. Gannett left for the field on July 2. He was instructed to continue the triangulation in western North Carolina and in the valley of East Tennessee. During the season he occupied 19 stations, controlling an area, within figures, of 5,000 square miles. The triangulation was carried on with a 7-inch theodolite, reading to 10″ by vernier. Artificial signals were used throughout, and in some cases it was necessary to use heliotropes, especially upon the low valley stations.

Mr. Griswold left for the field on July 1, his point of outfitting being Cumberland, Maryland. While engaged in preparations for taking the field, he did some topographic work in the vicinity of Cumberland, and left for the field, with his party fully organized, on July 16. His party consisted, besides himself, of Messrs. L. C. Fletcher and Merrill Hackett, assistant topographers, with two field assistants and the necessary laborers. During the season he completed the triangulation and topography of 3,540 square miles, comprised in the counties of Alleghany and Washington, in Maryland; Mineral, Hampshire, Preston, Tucker, Grant, Hardy, and Morgan, in West Virginia; and Warren, Frederick, Shenandoah, and Page, in Virginia. The party was disbanded at Romney, West Virginia, November 29. Mr. Griswold remained in the field until December 9, with one assistant, for the purpose of closing up the triangulation.

The party of Mr. Bien consisted, besides himself, of Messrs. R. C. McKinney and E. A. Oyster, with several field assistants and the necessary laboring force. The general section of work was southwest Virginia. He completed an area of 2,920 square miles, comprising the whole or parts of Scott, Washington, Smythe, Tazewell, Bland, Wythe, Grayson, Carroll, Pulaski, and Giles Counties. His party was disbanded at Wytheville, Virginia, on December 5.

The party under Mr. Shumway outfitted at Charleston, West Virginia, and commenced work on August 1. Mr. Shumway's assistants were Messrs. G. F. Wakefield, D. C. Harrison, and E. C. Barnard, besides several field assistants and the necessary laborers. The party was large one, intended to carry on both triangulation and topography, Mr. Wakefield having been detailed to it primarily for the purpose of doing the former work. Mr. Shumway's field of work lay entirely in the Cum-


PROGRESS SKETCH
showing
CONDITION OF THE TRIANGULATION
in the
APPALACHIAN DIVISION
to date of Dec. 1st.
1884
U.S. Coast and Geodetic Survey
U.S. Geological Survey
Common points of U.S.G.S and U.S.C.&G.S.
Scale.
OHIO
INDIANA
KENTUCKY
WEST VIRGINIA
VIRGINIA
TENNESSEE
GEORGIA
SOUTH CAROLINA
KNOXVILLE
CHATTANOOGA
LYNCHBURG

berland plateau region, part of it being in West Virginia, between the Big Sandy and Kanawha Rivers, and partly in eastern Kentucky. The total area of this most difficult country surveyed by the party during the season was 3,250 square miles, comprised in the counties of Letcher, Knox, Floyd, Pike, and Martin, in Kentucky; and in Wyoming and McDowell Counties, in West Virginia. The party disbanded early in December. Mr. Shumway remained in the field a short time thereafter and Mr. Wakefield until the end of the calendar year, for the purpose of closing up gaps in the triangulation.

Mr. Pearson's party comprised besides himself Messrs. H. B. Blair and A. E. Murlin, two field assistants, and laborers. Mr. Pearson was occupied with general executive duties relating to the division, so that his party was not able to commence work until August 5. His field lay in the valley of East Tennessee, extending southwestward from that of last year. The area surveyed comprised the whole or parts of the following counties: McMinn, Monroe, Loudon, Blount, Sevier, Cocke, Green, Washington, and Unicoi, being a total area of 3,000 square miles. His party disbanded at Athens, Tennessee, December 1.

Mr. Yeates was assisted by Messrs. R. McC. Michler, H. S. Selden, S. H. Giesy, and S. J. Wilson, assistant topographers, and the necessary laboring force. His field of work lay in the southwestern portion of the mountain region of North Carolina and northeastern Georgia. In the former State he completed the counties of Cherokee, Graham, and Clark, and portions of Monroe, Swain, and Macon, and in the latter State parts of the counties of Fannin, Union, and Towns. The total area surveyed by this party was 1,930 square miles. It disbanded at Charleston, North Carolina, November 27.

The party under Mr. Nell comprised besides himself Mr. R. M. Towson, assistant topographer, four field assistants, and the necessary laboring force. It was outfitted at Chattanooga, Tennessee. The field of work lay directly south of that point, in northeastern Alabama and northwestern Georgia. In the former State Mr. Nell was aided to a considerable extent by the drainage furnished by the plats of the General Land Office, while the triangulation of the United States Coast and Geodetic Survey furnished the necessary control. During the season this party mapped a small area in Tennessee, in the vicinity of Chattanooga; the counties of Jackson, De Kalb, Etowah, and Cherokee, in Alabama; and Dade, Walker, Chattooga, Floyd, and Polk, in Georgia, comprising an area of 3,000 square miles. The party was disbanded at Chattanooga, Tennessee, on November 24.

Base stations for the barometric work were established at Romney, West Virginia; Louisa, Kentucky; Wytheville, Virginia, and Charleston, North Carolina.

Through the co-operation of the United States Signal Service, the observations at their stations at Knoxville and Chattanooga were made available for our purposes, and proved of great assistance.

The triangulation this year, as heretofore, has been based directly upon the Appalachian and transcontinental belts of the United States Coast and Geodetic Survey. The triangulation of the parties of Messrs. Gannett, Griswold, and Shumway covers within figures an area of 8,900 square miles. The average error of closure, after correcting for spherical excess, was 15″ or 5″ to each angle.

The total area surveyed and mapped by this division during the season was 17,640 square miles. While this area does not compare favorably in square miles with those of other divisions, it should be remembered not only that the scale is larger than is employed in other fields, but also that the country is perhaps the most difficult for the surveyor to be found upon the continent. The practical difficulties of the work in this region not only call forth all of a man's best qualities, but to make even a fair rate of progress requires most unwearied energy and activity. The total cost of field and office work averages about $3 a square mile.

The work has been done with a view to publication upon a scale of 1:125000, or about 2 miles to an inch, in contours 100 feet apart. The total area surveyed in this field, since the inception of work there, is 35,380 square miles. This is distributed as follows among the States lying in this region:

	Square miles.		Square miles.
Alabama	2,080	North Carolina	5,930
Georgia	1,370	Tennessee	8,070
Kentucky	1,420	Virginia	7,360
Maryland	1,150	West Virginia	8,000

During the winter the work of the preceding field season has been plotted up, and, in addition, the greater part of the work heretofore done has been replotted and redrawn in contours with vertical intervals of 100 feet. This has entailed for this division double duty in the office.

On the 1st of May of the current year Mr. S. S. Gannett, topographer, was sent into the field for the purpose of completing the triangulation in the lower part of the valley of Tennessee and making connection with the points established by the United States Coast and Geodetic Survey in northern Georgia and Alabama. This portion of his work is now complete.

Early in June Messrs. Griswold and Fletcher left for the field for the purpose of closing up gaps in the triangulation in northern West Virginia, a work upon which they are at present engaged.

SOUTHWESTERN DIVISION.

The increased allotment for geographic work rendered it possible to commence work in Kansas, Missouri, and Texas. The work in these areas as well as that in the plateau region was placed in immediate charge of Prof. A. H. Thompson, geographer.

Missouri-Kansas section.—In those States and Territories which have been surveyed by the public land system it seemed possible to expedite the work very greatly, without sacrificing its accuracy in the least, by a proper use of the plats of the General Land Office. An examination of them showed that they furnished at least the major part of the drainage in sufficient detail for maps upon a scale of 1:125000. It appeared that by supplying a proper system of correction for these surveys, by supplying the missing drainage wherever it appeared to be necessary, and by adding the vertical element the resulting maps would be fully up to the proposed scale in point of accuracy and detail. This conclusion was not arrived at hastily, but was reached after testing the surveys made in the various parts of the country with considerable care.

In accordance with this conclusion, Mr. R. U. Goode was appointed and directed to take charge, under Professor Thompson, of the topographic work to be done in Missouri and Kansas. For carrying on the work in this region two parties were organized, of one of which Mr. Goode took immediate charge, the other being under Mr. W. J. Peters, assistant topographer.

For the control and correction of the surveys of the General Land Office it was decided tentatively to use astronomic locations, and for the purpose of making these determinations Prof. R. S. Woodward, formerly assistant on the United States Lake Survey, was appointed and detailed. During the season he made five determinations of position, viz, Elk Falls, Oswego, and Fort Scott, Kansas; Springfield and Bolivar, Missouri, using the Saint Louis observatory as the base station for longitude determinations.

The following are the positions determined:

	° ′ ″	° ′ ″
Elk Falls, Kansas	37 22 03.64	96 11 09.37
Oswego, "	37 09 59.81	95 06 19.95
Fort Scott, "	37 50 25.76	94 42 21.06
Springfield, Missouri	37 13 15.96	93 17 12.37
Bolivar, "	37 36 35.22	93 24 42.60

The stations selected were near the limits of the area to be surveyed and at the same time as near as possible to correction lines and guide meridians of the land surveys. These stations were connected by triangulation with township corners.

The topographic work, which consisted almost entirely of hypsometry, went on with great rapidity. Mr. Goode surveyed the two square degrees 93°–37°, and 94°–37°, comprising an area little less than 8,000 square miles, and Mr. Peters the entire square degree 95°–37° and nearly half of 96°–37°, being an area of 5,600 square miles. The cost of this work in both the field and the office was less than $1 per square mile. In fitting the township surveys to the astronomic positions it was found that the errors of the former were very slight, so small indeed that the system of control was found to be ample for the purpose.

During the month of November these parties were disbanded and returned to Washington. During the winter and spring Professor Woodward has been employed in reducing his astronomic work and Messrs. Goode and Peters in plotting their maps.

Early in June Professor Woodward was detailed for the purpose of making an astronomic determination of the position of Albuquerque, New Mexico, upon which he is at present engaged.

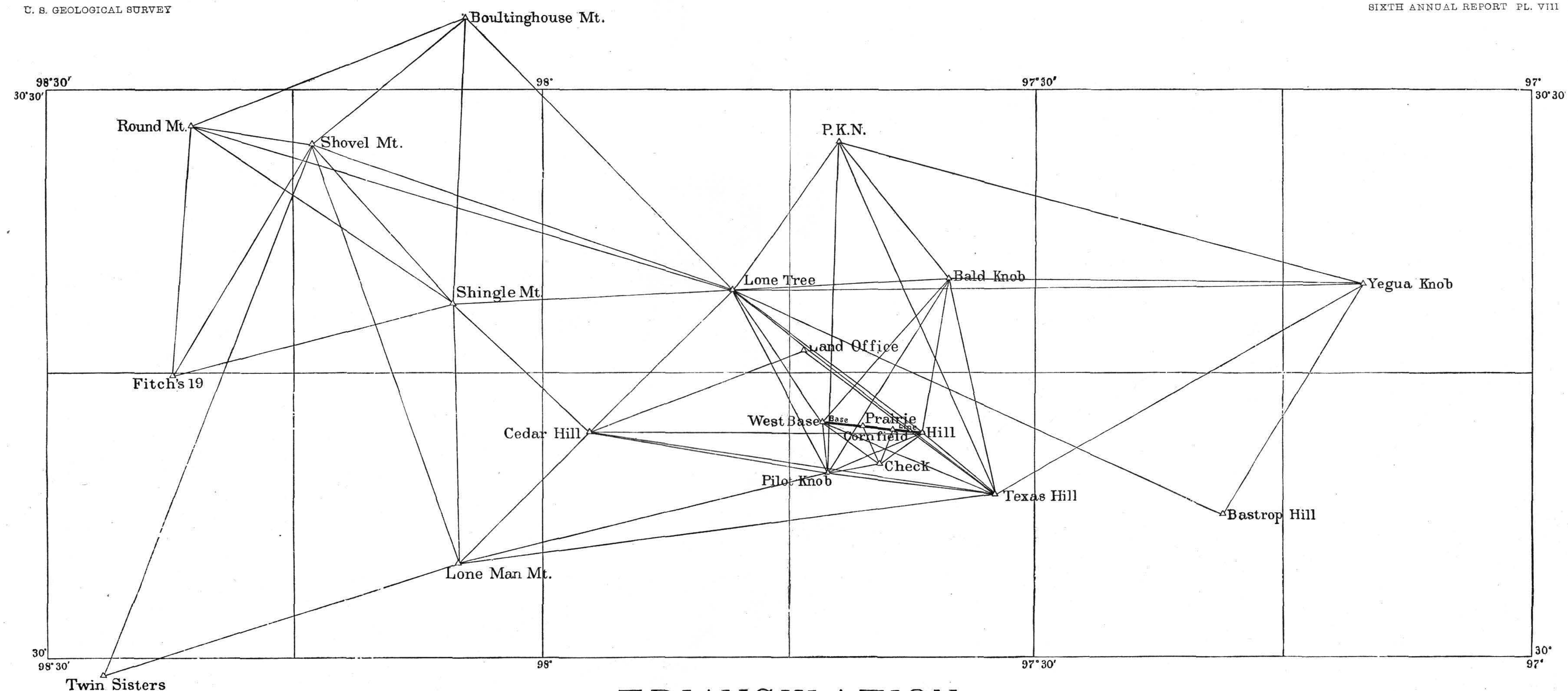
Texas section.—The projected work in Texas was put in immediate charge, under Prof. A. H. Thompson, of Mr. E. M. Douglas, topographer. Three parties were organized: one for triangulation, under Mr. Douglas's immediate charge, the other two for topographic work, respectively under Messrs. A. F. Dunnington and C. H. Fitch, topographers. Work was commenced near Austin in the latter part of July; a location for a base was selected and it was at first roughly measured with a steel tape and an expansion made for the immediate purpose of furnishing the plane tablers with located points. Thus supplied with locations, the topographic parties worked during the season, covering an aggregate area of about 4,000 square miles. In the mean time Mr. Douglas expanded the base carefully and covered the surveyed area with a system of triangulation. At the close of the field season, after the parties had disbanded, the base was accurately measured with four-meter bars.

The apparatus used in this work is the ordinary secondary slide-contact base apparatus, as designed by the United States Coast and Geodetic Survey and described in their reports.

The place selected for the measurement of the base line is in the valley of the Colorado River of the South, southeast of Austin. Commencing at a point on the west bank of Onion Creek, about a mile north of where the Austin and Bastrop road crosses and about 9 miles from Austin, the line runs nearly due west to the west base station, a distance of 9,884.85 meters (=6.2 miles).

The base line was extended eastward by triangulation 422.2 meters, to the top of a hill on the south bank of Onion Creek. The ends of the base are marked on copper bolts set in stones in the ground. Besides these there are four reference stones, two in the line of the base and two nearly at right angles to it.

The whole line was measured once, and the middle third of it a second time. The two measurements of the middle third, after having been corrected for slope and temperature of the measuring bars, differed only 0.021 meter, about 0″.8. The length of the whole line, including the extension at the east end, was then calculated from this twice-measured line by means of a system of triangulation, the resulting length being 0.174 meter (about 25″.8) less than the measured length. It was assumed that the errors of the triangulation were ten times as



TRIANGULATION
in the
VICINITY OF AUSTIN TEXAS
1884-5
E. M. DOUGLAS TOPOGRAPHER

Scale
0 1 2 3 4 8 12 Miles.

great as those of measurement. Hence, combining the results in these proportions, the weighted length of the base line is 10,307.201 meters.

The measuring bars were compared with the standard bar in the Coast and Geodetic Survey Office in January, 1884, and again in April, 1885, the mean difference in the lengths of the bars as determined by these comparisons amounting to .000018 meter.

The men engaged in the work were as follows: One chief of party, one recorder, one transit-man, one scale reader, and three laborers. The average distance measured per hour was 132 meters (about 433 feet).

Mr. Douglas occupied during the season in the expansion and extension of his triangulation twenty-five stations, most of which are represented upon the accompanying diagram (Plate VIII). The triangle sides, with the exception of the expansion, range in length from 11 to 38 miles, the average length of a side being about 25 miles. The average error of closure of all the completed triangles, after allowing for spherical excess, is 8″.5.

The topographic work was done with the plane table, supplemented by traverses along the roads in the level and timbered regions.

Work was continued in this field until the early part of January, and, after the topographic parties were disbanded, Mr. Douglas found it necessary to remain until the middle of the following month for the purpose of completing the triangulation.

Arizona section.—The projected work in the plateau region comprehended the filling out and completion of a number of atlas sheets which had been in an unfinished state: the western half of atlas sheet 109°—37°, all that part of 110°—37° and 111°—36° lying east of the Colorado River, the southern half of 113°—35°, the southern and western three-fourths of 114°—35°, and the western half of 114°—36° being the areas to be surveyed. In addition to this, the triangulation over the area surveyed during the previous season was in an uncompleted state and required revision, while a considerable extension of it was demanded to control these additional areas.

The duty of revising and extending this triangulation was intrusted to Mr. Arthur P. Davis, topographer, with Mr. James A. Maher, assistant topographer, as assistant, and was performed in a very satisfactory manner. In the prosecution of the work he occupied twenty-nine stations, distributed over the country from the La Sal Mountains on the north and Navajo Mountain on the west to the 35th parallel on the south and the 109th meridian on the east. The area covered within figures was approximately 29,000 square miles. The greatest length of line observed each way was 137 miles (Mount Waas to Navajo Mountain), while the average length of triangle sides was 54 miles. The mean error of closure of triangles, after correcting for spherical excess, was 9″.55. Full connection was established between the work of the Hayden and the Powell Surveys.

The topographic work north of the thirty-seventh parallel was done by Mr. Paul Holman, assistant topographer, with Mr. H. L. Baldwin as assistant, and the survey of the eastern portion of sheet 111°—36° was effected mainly by Mr. Baldwin.

To the party under Mr. H. M. Wilson, topographer, was assigned the triangulation and survey of the unfinished portions of sheets 113°—35°; 114°—35°, and 114°—36°. As a base for the triangulation, he assumed the line Brink-Emma, the length of which had been determined by the Powell Survey, and carried the work thence southward and westward. For the primary control of the work Mr. Wilson occupied ten stations. The relief of the country was such that very long lines could be easily observed, and the average length of the sides of his triangles was 70 miles. The average error of closure of the triangles in this work was about 27″, a large error, even when it is remembered that natural points were in all cases sighted.

Prior to commencing this general work Mr. Wilson made a detailed map of an area of 750 square miles, including and surrounding the San Francisco peaks in Arizona, upon a scale of 1 mile to an inch, in contours 100 feet apart vertically.

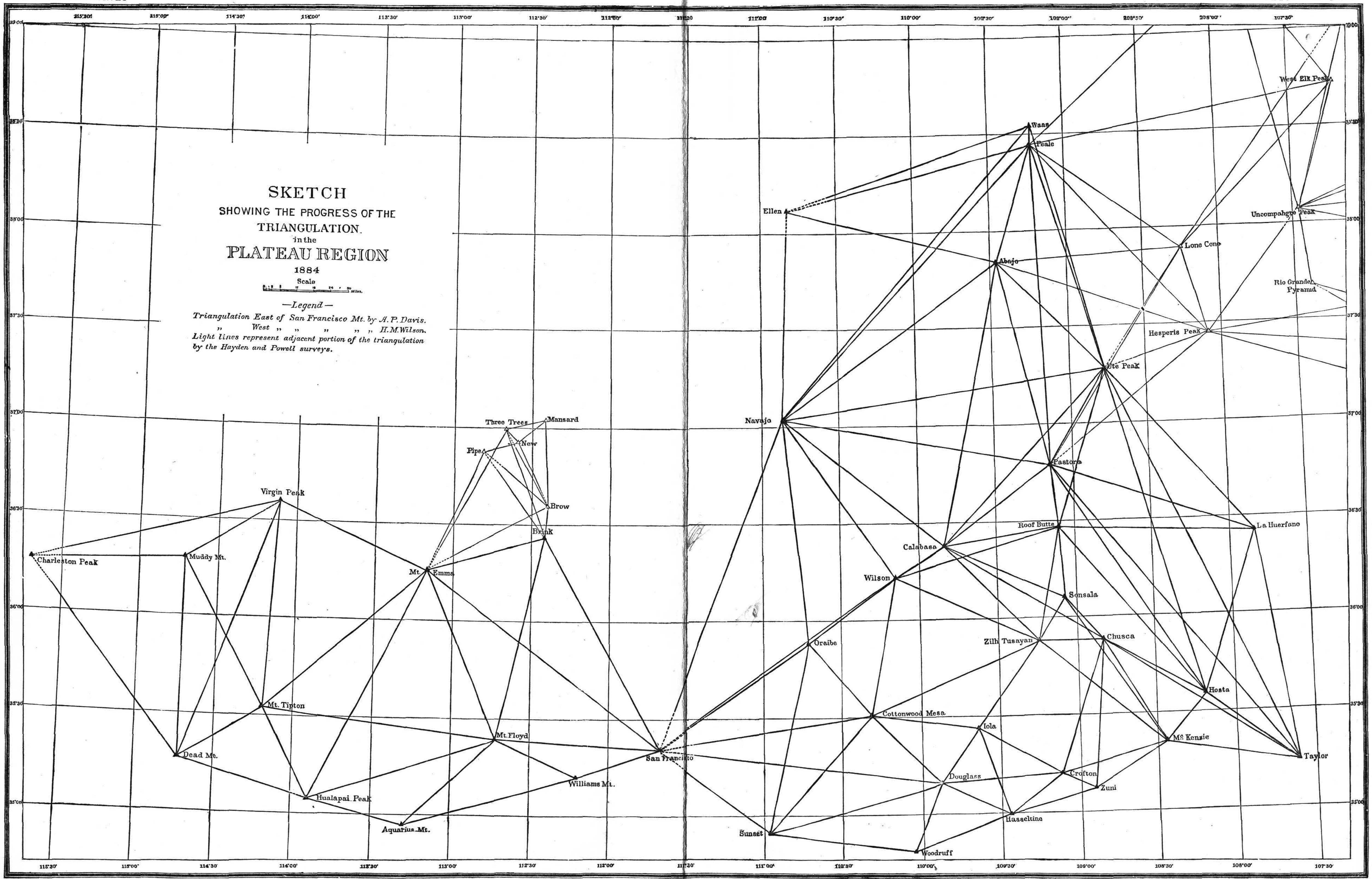
The total area surveyed by this section was 15,000 square miles, of which 5,000 are to be credited to Messrs. Holman and Baldwin, 3,000 to Mr. Baldwin alone, and 7,000 to Mr. Wilson, exclusive of the San Francisco map. This work has been done, as heretofore, with a view to publication upon a scale of 1: 250,000, in contours 250 feet apart vertically.

The parties were late in disbanding. Mr. Baldwin's party was broken up in the middle of December, while Mr. Wilson's party reached Kanab, Utah, having completed their work, on December 7, after which he was obliged to travel overland, through the snow, to Fort Wingate, New Mexico, where he disbanded, the journey occupying twenty-two days. Mr. Davis' party remained in the field for the purpose of completing their triangulation until early in March, having been delayed very greatly by heavy snows after the opening of winter.

YELLOWSTONE DIVISION.

This work has been in charge of Mr. John H. Renshawe, geographer, to whom were assigned as assistants Messrs. S. A. Aplin and Frank Tweedy, assistant topographers, and Ensigns H. S. Chase and Leroy M. Garrett, U. S. Navy. During the month of May Ensign Chase, with Ensign Garrett as assistant, had been sent into the field for the purpose of extending the triangulation and establishing a stronger connection between the expansion at Bozeman and the stations within the Park. This work he successfully accomplished prior to the arrival of the main body of the party.

On July 16, Mr. Renshawe, with Messrs. Aplin and Tweedy and a number of field assistants, left Washington for the resumption of field work. After outfitting at Bozeman, Montana, they drove to Mammoth


SKETCH
SHOWING THE PROGRESS OF THE
TRIANGULATION
in the
PLATEAU REGION
1884
Scale
Miles.
—Legend—
Triangulation East of San Francisco Mt. by A. P. Davis.
" West " " " " " H. M. Wilson.
Light lines represent adjacent portion of the triangulation by the Hayden and Powell surveys.
Waas
Peale
West Elk Peak
Uncompahgre Peak
Ellen
Lone Cone
Abajo
Rio Grande Pyramid
Hesperis Peak
Ute Peak
Navajo
Three Trees
Mansard
New
Pipe
Pastora
Virgin Peak
Brow
Brink
Roof Butte
La Huerfano
Calabasa
Charleston Peak
Muddy Mt.
Mt. Emma
Wilson
Sonsala
Oraibe
Zilh Tusayan
Chusca
Hosta
Mt. Tipton
Cottonwood Mesa
Iola
Mt. Floyd
Mc Kensie
Dead Mt.
San Francisco
Taylor
Crofton
Williams Mt.
Douglass
Zuni
Hualapai Peak
Hasseltine
Aquarius Mt.
Sunset
Woodruff

Hot Springs, the point for resuming work, arriving on the last day of the month. It was the intention during the season to complete that part of the Park lying west of the Yellowstone River and Lake, but, unfortunately, on the 21st of August, less than three weeks after commencing work, Mr. Renshawe was taken seriously ill with typho-malarial fever, and was taken back to the Mammoth Hot Springs, where he remained until the close of the season. Meantime his party was in charge of Ensign Chase, who carried on the work. The work, however, necessarily suffered for the want of Mr. Renshawe's immediate supervision and his personal aid. The completed area, however, was extended eastward to the Yellowstone River as far as its head, and around Yellowstone Lake as far as Flat Mountain. Thence the line of completed work runs in a general westerly and northwesterly course, embracing the Red Mountains and the greater part of the shore of Shoshone Lake. The area surveyed during this season comprises about 1,000 square miles.

During September snow-storms began to be prevalent in the Park, and early in October the party gave up work, disbanded, and returned to Washington. During the winter the triangulation was reduced and the field work plotted up, and during the spring the members of this division were engaged in compiling and revising the sheets of the Hayden survey in Colorado preparatory to having them engraved.

CALIFORNIA DIVISION.

Mr. Gilbert Thompson, geographer, having been detailed to the charge of the Appalachian Division, the work in northern California was placed in immediate charge of Mr. Mark B. Kerr, topographer, with the understanding that Mr. Thompson was to continue to exercise general supervision. Messrs. Eugene Ricksecker and Jeremiah Ahern, assistant topographers, were detailed as assistants in this work. Two parties were organized, one under Mr. Kerr, which was to carry on general work designed for publication, upon a scale of 1:250000, in contours 200 feet apart, and the other, under Mr. Ricksecker, to make a map of Mount Shasta and its immediate surroundings, upon a sufficiently large scale to be published upon a scale of 1:62500. Mr. Kerr left for the field in the latter part of June, the outfitting point being, as heretofore, Red Bluff, California. Mr. Ricksecker arrived at this place on July 16, and one week later started for his field of work at Mount Shasta. During the season he surveyed an area, embracing the mountain, of about 400 square miles. The work was done with the plane table, upon a scale of 1:20000, and contours were drawn at vertical intervals of 100 feet.

I regret to record the death of Mr. Ricksecker's assistant, Mr. Howard N. Pomeroy, assistant topographer, who was killed by the accidental discharge of his rifle on August 25th while engaged upon his work. It appears that Mr. Pomeroy was alone, and was at the moment leading his mule down a steep bank, through chaparral, with his loaded gun upon the pommel of the saddle; that the hammer was caught and then fell, discharging the gun. The ball entered his left leg above the knee and severed the femoral artery, causing him to bleed to death. Mr. Pomeroy was a resident of San Francisco, and entered the service through a civil service examination. He was a very promising assistant. His death at any time would have been a misfortune to the service, and coming as it did in the middle of a field season, it was a most serious loss to the work upon which he was engaged.

Mr. Kerr's party left Red Bluff immediately after Mr. Ricksecker's, and prosecuted field work continuously until the close of the season. As is usual in the Cascade and Coast Ranges, there was much smoky and hazy weather, especially in the latter part of the summer and in the fall, which considerably delayed the work and especially had a bad effect upon the triangulation. In spite of this, however, Mr. Kerr was moderately successful, covering an area of 3,350 square miles. Besides this, two stations were occupied for the primary triangulation.

This area is comprised mainly in the broken mountainous country lying west and southwest of Mount Shasta.

The parties disbanded early in November, and were at once ordered to make surveys of certain quicksilver districts in California and Nevada. These are as follows: The district known as Steamboat Springs, in western Nevada, of which a map covering an area 4 miles by 3, on a field scale of 800 feet to an inch, was desired; second, the Oat Hill district, California, comprising an area of 1 mile by 1½, also upon a field scale of 800 feet to an inch; third, the Great Western district, comprising a similar area upon the same scale.

The first of these maps was made mainly by Mr. Ricksecker, with some assistance from Mr. Kerr, while the Oat Hill map was made by Mr. Kerr and the Great Western map by Mr. Ahern. The work was done with the plane table. The parties completed field work and reported in Washington shortly before the close of the calendar year.

DISTRICT OF COLUMBIA.

Early in May of the present year it was decided to resume work in the neighborhood of the District of Columbia, with a view to completion, upon a scale of 1:62500, of the two atlas sheets lying between latitudes 38° 45′ and 39° and longitudes 76° 45′ and 77° 15′. This work was placed in charge of Mr. John D. Hoffman, topographer (under the general direction of Mr. Gilbert Thompson), and to him were detailed Messrs. D. J. Howell, Jeremiah Ahern, S. J. Wilson, and several rodmen. Work was commenced in the southwestern part of the area and is being prosecuted rapidly.

DRAUGHTING DIVISION.

The draughting division has been occupied during the year with a great variety of work. Owing to the fact that the plotting of the field work and the completion of the original map are done by the topographers themselves, the draughtsmen have little to do with the original work. Their duties have related mainly to the preparation of map illustrations, in large part for the geological divisions. In addition to this, considerable progress have been made in the compilation of a map, upon a scale of 1:1000000, of the United States; transcripts of the original sheets of the Massachusetts survey have been made for deposit with the State of Massachusetts, and much work has been done in the way of revision of the map sheets of the Hayden Survey, with a view to re-engraving them upon copper.

INSTRUMENTS.

The matter of the supply, and especially of the repair, of instruments has been from the inception of topographic work a somewhat embarrassing one, and the necessity of having a mechanician connected with the Survey has long been apparent. Finally, upon the 1st of March of the present year, Mr. Edward Kübel, a well known instrument maker, who, from long association with this organization and its predecessors, was well acquainted with the instruments and methods in use, was appointed mechanician. His time, since his appointment, has been fully taken up with repairs of instruments required for use in the field during the present season.

ENGRAVING.

Plans having been matured by the Public Printer for the engraving of the topographic maps of the survey, contracts have been made by him with Messrs. Bien & Co., of New York, for the engraving of 100 atlas sheets upon copper. Of these, seventeen have been transmitted to Messrs. Bien & Co., and the engraving is now in progress, while the manuscript maps for the rest are now completed and are ready for transmission.

It is believed that, with the present appropriation for topographic work, areas comprising one hundred sheets can be surveyed each year, and the maps prepared for the engraver.

Very respectfully,

HENRY GANNETT,
Chief Geographer.

Hon. J. W. POWELL,
Director United States Geological Survey, Washington, D. C.

REPORT OF PROF. RAPHAEL PUMPELLY.

UNITED STATES GEOLOGICAL SURVEY,
ARCHÆAN DIVISION,
Washington, D. C., July 1, 1885.

SIR: I have the honor to submit the following report of my division during the past year.

The division was organized during the summer of 1884 by the appointment of myself in July and of my assistant, Mr. Bayard T. Putnam, in the autumn.

I have devoted the year to work in two directions:

1. I was engaged in completing the volume on mining industries intrusted to me jointly by the Geological Survey and the Census Bureau. A large part of the manuscript for this volume had been finished for two years or more, but the loss of some of the manuscript and illustrations rendered a revision and partial rearrangement necessary. This work has occupied almost exclusively the attention of my small office force through the winter and spring. Much valuable new matter has been added, and I hope soon to have the whole manuscript in the hands of the printer. The volume will contain, besides the statistics of the mines of coal, iron-ore, copper, lead, zinc, and the lesser minerals, the results of special field and chemical investigations into the iron-ore resources of the Republic and into the Cretaceous coals of the Northwest.

2. A beginning was made in the geological work of my division last summer and autumn by reconnaissances in the field in the Monadnock and Kearsarge districts.

During the coming season there will be four parties, besides some volunteer assistants on preliminary work. It is proposed to devote the greater part of our time to the study of the structural relation of the Taconic group to the rocks lying to the east and west.

In addition to the field work, I hope to have the preliminary work under way preparatory to surveying the areal geology of the sheets already finished of the Massachusetts map.

I have the honor to be, your most obedient servant,

RAPHAEL PUMPELLY.

Hon. J. W. POWELL,
Director United States Geological Survey, Washington, D. C.

REPORT OF PROF. N. S. SHALER.

UNITED STATES GEOLOGICAL SURVEY,
ATLANTIC COAST DIVISION,
Cambridge, Mass., June 30, 1885.

SIR: I have the honor to submit the following report concerning the geological investigations committed to my charge during the last fiscal year.

On the receipt of my appointment and instructions I at once began work on the geology of the Atlantic coast line. During the summer months my time was given to the study of the geology of the region near Eastport, Maine. The most important results of this inquiry have already been submitted in the form of a preliminary report on the geology of the Cobscook district. This region was found to afford an entirely unexplored geological field full of facts of great scientific interest. Several paleozoic horizons abounding in fossils, a remarkable series of volcanic and trappean rocks, together with many singular structural features of the deposits, have been noted in the report above referred to.

Work in the Cobscook Bay district was not extended beyond the stage of a preliminary reconnaissance for the reason that there is as yet no trustworthy map of the district on which the geology can be delineated, even in the most general way. The extreme complication of the shore line and the remarkably detailed character of the important geological features made it impossible to prepare a sketch map which could be made to serve the needs of a preliminary delineation.

After closing this preliminary work in the Cobscook Bay district I began the study of the district adjacent to Narragansett Bay. For many years I have been engaged in occasional studies in this interesting field, but I have never before seen the opportunity of bringing my inquiries to a successful issue. The economic importance of this field lies in the fact that it contains a large and essentially unexplored coal basin, which may have a great value to the future of New England industries. What I have already done has shown me that this basin contains several coal-beds of workable thickness which underlie a large area. The coal is exceedingly anthracitic, but careful experiments show that it has a heat-giving power which is about equal to 80 per cent. of the calorific value of the best Pennsylvania anthracites. These coal-beds lie in strata which are very much dislocated, and in parts of the basin they are rendered useless by the crumpling and cracking which have accompanied the folding to which they have been subjected; still, there are large areas where the beds appear to lie in attitudes which will not make the mining difficult. Analyses and experiments appear to show that the Narragansett coal-field has peculiar advantages for use in making water gas and in smelting iron and copper. It is singularly compact, its specific gravity being about 25 per cent. greater than that of the Pennsylvania anthracites; it therefore will not fill up a furnace to the same extent as the other coals of the same nature, and it remains a long time in combustion. The percentage of sulphur is low, and the proportion of ash is not greater than that of several coals which are extensively used in this country.

It is interesting to note that this is the only coal-field on the Atlantic coast of the United States which is actually on tide water. In the same basin there are extensive deposits of iron ore which may prove to be valuable, and in immediate connection with these there are excellent and cheaply quarried beds of limestone; there are also fire-clays, which are as yet but little explored.

These natural resources of the Narragansett Bay were long ago the subject of many commercial misadventures which have led to their neglect in later times. In large part these failures were the result of serious blunders such as are quite evitable at the present time. It seems to me that the problems connected with this coal and iron field demand a far more careful geological study than they have ever received and that from such study may come results of great economic importance.

The study of this basin is made exceedingly difficult by the fact that nearly the whole of its area is covered by a very thick coating of rearranged glacial drift, which often makes it impossible to get any knowledge of the geology of the bedrocks; at several points where it is of great importance to have a knowledge of the underlying strata there are absolutely no exposures of them.

In the course of my explorations in this field I have been so fortunate as to obtain a series of diamond-drill borings, in large part made under my own direction, which give in the aggregate about 4,000 feet of clear and continuous section in very important parts of the district. These sections show that it will be easy, and in view of the importance of the problem inexpensive, to secure in this way a sufficient acquaintance with these Carboniferous strata to determine the value of the coals which they contain. Although this particular task lies beyond the province of the Geological Survey, it is to be hoped that the preliminary report of this field will lead the local authorities of the district to undertake these explorations by means of the drill, and thus lay the basis for the final determination of these economic problems.

The Carboniferous rocks of this basin which probably contain coal-beds cover an area of about 800 square miles. The total thickness of the section which is presumably coal-bearing exceeds 5,000 feet. It is not likely that, from the incomplete exploration which has been made, we as yet know one-fourth of the coal-beds of a workable nature.

I hope to have the preliminary report on this basin in a state for publication at the close of the next official year, although it may be delayed by the incompleteness of the topographic work in this district; so much of the topography of this coal basin as lies within the State of Massachusetts will be ready for use by the next winter or spring, but a portion of the basin which lies in the State of Rhode Island, and is not included in the Coast Survey maps, will then be wanting. It seems to me very desirable that the topographic work of the Geological Survey should as speedily as possible be extended over this district, for until it is done even a good preliminary report on this Carboniferous basin cannot be completed.

During the winter season some studies have been made on the marshes of New England; the results of these studies have been given in a preliminary report for immediate publication. The sea-board and inland marshes of the United States constitute a considerable portion of its area. A large portion of these swamp lands are of a nature which admits of improvement for agricultural purposes. Much of the area of extremely fertile lands of northern Europe, especially in Great Britain and the low countries near the mouth of the Rhine, was originally in the unprofitable condition in which the American swamps remain.

The total reclaimable area of salt-water swamps of New England probably exceeds 300,000 acres, and the area of such lands on the whole coast of the United States, excluding Alaska, is perhaps twenty times as great. The unimproved but improvable fresh-water marshes of the United States—such lands as have yielded the finest tillage grounds of northern Europe—amount in area to many thousand square miles. On a rough computation, from the extremely imperfect topographical maps which now exist, it appears likely that the reclaimable swamps of the United States east of the one hundredth meridian, including in this class all inundated lands such as in northeastern Europe would ere this have been won to agriculture, exceed 20,000 square miles and may amount to nearly twice that area. These swamp lands, when won to agriculture, will have a food giving value much exceeding any equal area of high-lying lands in this country. With few exceptions, such districts have all the elements of extremely fertile soils in their composition, and need little more than proper drainage to bring them to a condition of great productiveness.

It is evident that these swamp lands contain dormant resources of a great state; it seems fit that their area and condition should be the subject of a careful inquiry, so that the facts may be presented not only from their purely scientific side, in itself a matter of great interest, but also that their physical and chemical condition may be so set forth that the economist may have the data necessary for his special work.

During the spring months of this year my work has been mainly upon the area of Martha's Vineyard, this being the most considerable geological unit of the New England district which has been accurately mapped.

The studies on Martha's Vineyard, though as yet incomplete, have afforded some very interesting results. The Tertiary strata at the west end of the island have a thickness of not less than 3,000 feet. They have been affected by considerable mountain building actions, the average dislocation from their original attitudes being as much as 20 degrees of inclination. It appears also that these Tertiary strata were in part formed from the waste of a district which contained an extensive field of new red sandstone and perhaps deposits belonging to later geological periods. This is shown by the abundant pebbles of rocks closely resembling the Connecticut sandstones contained in the beds; many of these pebbles exhibit recognizable plant fossils.

Besides the very interesting scientific questions connected with these deposits they afford some important economic problems which deserve attention. These Tertiary strata contain a great variety of fire-clays suitable for pottery use. It seems possible that there may be some useful marls to be found among the great variety of deposits which occur here. None of these beds have as yet been tested, either in the laboratory or in a practical way. The considerable quantity of vertebrate remains which are found in certain thick beds of this series makes it well worth while to see whether they may not afford a source of phosphatic manures.

Certain of the beds of this section, those containing a large amount of vegetable matter, are remarkably rich in alum. These clays were many years ago used in the production of commercial alum, but it was found that there was too much iron in the beds used to make the results satisfactory. It seems quite possible, however, that this objection only applies to certain beds which are exposed in the cliffs at Gay Head. There are many other parts of this section rich in alum which have not yet been examined.

This interesting section of the Gay Head and Chilmark beds is the only part of the Tertiary deposits of the eastern United States where a very thick section is exposed within a limited field, for the reason that it is here alone that these beds have been tilted at a considerable angle to the horizon. This makes it possible to obtain a more complete account of the geological structure and economic resources of the formation than can be had in any other portion of the Atlantic Tertiary deposits. Therefore it seems to me desirable that this section should receive very careful attention.

Very respectfully, your obedient servant,

N. S. SHALER,
Assistant United States Geological Survey.

Hon. J. W. POWELL,
Director of the United States Geological Survey, Washington, D. C.

REPORT OF MR. G. K. GILBERT.

UNITED STATES GEOLOGICAL SURVEY,
APPALACHIAN DIVISION,
Washington, D. C., July 1, 1885.

SIR: I have the honor to submit the following report of work under my charge during the fiscal year ending June 30, 1885. This pertains to two fields, in the first of which investigation has been terminated, while in the second a new work is being organized.

DIVISION OF THE GREAT BASIN.

Ever since the institution of the Survey, a corps has been engaged in studying the Quaternary history of the Great Basin. The last field work was performed in 1883, and the only function of the corps during the past year has been the preparation of final reports on its work.

An essay by myself on the topographic features of lake shores was submitted a year ago for publication in the fifth annual report, but was not immediately printed; and the delay in publication was utilized in supplementing its meager series of illustrations. For this purpose, Mr. I. C. Russell visited the shores of Lake Michigan and Lake Superior with the camera, photographing several topographic types described in the text, and from these photographs wood engravings were made.

A final report on the geology of Lake Lahontan by Mr. Russell has been submitted for publication as a monograph and is now in press. An outline of its contents appeared in the Third Annual Report, but the final memoir gives a fuller development to several topics, and especially to the chemical history of the lake and to the subject of playa deposits.

Another report by Mr. Russell, having for its subject the Quaternary geology of the Mono Basin, is now nearly ready. It gives an account of the ancient expansion of Mono Lake, of the Quarternary glacial system of an adjacent portion of the Sierra Nevada, and of the structure and history of the chain of volcanoes known as the Mono Craters.

Mr. R. Ellsworth Call's paper, on the existing and Quaternary mollusca of the Great Basin, which was ready for publication at the beginning of the fiscal year, has since appeared as Bulletin No. 11. It gives a systematic list of the shells heretofore discovered, describes a new species and two varieties, and discusses the cause of the depauperation of the Quaternary shells.

Prof. Edward S. Dana has likewise completed his investigation of the calcareous pseudomorph called thinolite, which has attracted so much attention on account of its relation to the chemical history of Lake Lahontan, and his report has been published as Bulletin No. 12.

A report on Lake Bonneville by myself will complete the series; besides describing and interpreting the phenomena which record the lake's history, it will discuss at length the relation of that history to the glacial epoch.

The maps necessary for the illustration of the Lahontan and Mono areas have been drawn by Mr. Willard D. Johnson, who had previously performed the field work. As the present organization of the survey relieves me of the supervision of topographic work, Mr. Johnson's connection with my corps ceases with the completion of these maps. I reluctantly yield him to the geographic division.

APPALACHIAN DIVISION OF GEOLOGY.

The new field of investigation assigned me is the general geology of the Appalachian Mountains, a work differing from my last not only in its character but in the fact that it already possesses a copious litera ture. It is proposed to utilize this literature to the fullest extent and execute no unnecessary field work. The amount of necessary field work is nevertheless large, and much attention has therefore been given to the elaboration of a comprehensive plan under which the geologists of the corps may work to the greatest advantage.

Previous to the creation of this division a number of assistants had been engaged in independent work falling within its topical and geographic limits, and these have by your direction reported to me for duty. Mr. Ira Sayles was attached to my corps in July, 1884, Mr. H. R. Geiger and Prof. I. C. White in August. Mr. Bailey Willis, who had been occupied with special investigations in Dakota, was assigned to the division in April, 1885, and Mr. I. C. Russell, who has continued as my assistant, began work in the eastern field in the same month.

Three short excursions have been made by myself. The first was a reconnaissance in the mountainous portion of western North Carolina, Tennessee, and Georgia, with special reference to the terrace system of the mountain valleys. I was absent from Washington from July 25 to August 17, 1884. A similar reconnaissance in New Hampshire, Massachusetts, and eastern New York consumed three weeks in August and September. The last week of May and the first week of June in this year were spent in eastern New Jersey and western New York, in the examination of evidences of post-glacial movements of the earth's crust.

Mr. Russell left Washington April 16, procured camping equipage at Knoxville, Tennessee, and crossed the mountains to southern North Carolina, where he spent a month in the study of the Triassic area in Anson, Montgomery, and Richmond Counties. He was then called to Washington to read the proof of his memoir now in press, in which work he is still engaged.

Mr. Willis took the field three weeks later, and likewise procured a camp outfit at Knoxville. His district is a belt of country 20 miles broad, and extending from the Cumberland plateau, north of Cumberland Gap, southeastward to the high mountains of North Carolina. In this district he studies the structural geology, the stratigraphy, and the textural changes due to metamorphism. He is still in the field.

Mr. Geiger continued in the field throughout the summer and autumn of last year and returned to Washington on the 30th of November, his district including the White Sulphur Springs of Virginia and having an extent of 20 miles in an east and west direction and 50 miles in a north and south direction. He was occupied with the investigation of the orographic structure and the stratigraphy, and he made valuable collections of fossils. The winter and a portion of the spring were consumed in the elaboration of his field notes and in other office work. On the 16th of May he took the field for a similar study in a new district, and he has been engaged up to the present time in an examination of the structure of the Blue Ridge from Staunton, Virginia, to Harper's Ferry, West Virginia. Mr. E. H. Andrews accompanies him as assistant.

From July 15 to December 26, 1884, Mr. Sayles studied the stratigraphy and structure of an area lying between the Holston and Nolichucky rivers, in East Tennessee. Near the end of April, 1885, he resumed work in a contiguous district, and he is still in the field. The interval was occupied with office duties, chiefly the elaboration of his notes and the preparation of his collections for installation in the National Museum.

Professor White, of the University of West Virginia, devoted his summer vacation in 1884 to the investigation of the stratigraphy of the coal measures in the valley of the Great Kanawha River in West Virginia. His field notes were afterward elaborated in such time as could be spared from his college duties, and he has submitted a report of his work. This will not be published at once, but is to be incorporated in a memoir on the stratigraphy of a larger area. On the 18th of June last he took the field again, and he is now engaged in the study of the Carboniferous strata of Pennsylvania along the Allegheny, Clarion, and Conemaugh rivers.

I remain, with great respect, your obedient servant,

G. K. GILBERT,
Geologist.

Hon. J. W. POWELL,
Director United States Geological Survey, Washington, D. C.

REPORT OF MR. W J M'GEE.

UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., June 30, 1885.

SIR: I have the honor to submit the following report of operations during the fiscal year terminating to-day.

The work of the year in office and field has been the extension and continuation of that undertaken during 1883–'84 and reported upon a year ago, together with (1) office work on lines related to those already in hand, (2) field investigations essential to the satisfactory execution of one of the office tasks assigned me, (3) field work in the region contiguous to, and geologically connected with, that previously allotted to me, and (4) a review of certain field operations of previous years.

OFFICE WORK.

The general map.—The geologic map of the United States described in a previous report has been lithographed, and in its first edition forms Plate II of the Fifth Annual Report of the Survey. This map is a perhaps ultra expression of the conviction of the author that the scale commonly adopted for maps printed in colors is too large, and that geologic maps and atlases are in consequence unnecessarily cumbrous and expensive. Accordingly the cartography is so fine that the lithographer, unaccustomed to such refinement, had difficulty and spent several months in transferring it. Six successive proofs required revision, and the revision of the earlier proofs was especially laborious. The final proofs are eminently satisfactory and reflect credit upon the lithographer. It is believed that such a map, combining as it does the comprehensiveness of the general map with the accuracy in detail usually attained only on much larger sheets, will meet the requirements of working geologists and instructors generally.

A large scale copy of the map (about 50 miles = 1 in. or 1: 3,168,000; dimensions, 5 feet 2 inches × 8 feet 3 inches) was prepared in September last for exhibition at the meeting of the American Association for the Advancement of Science and for subsequent use in this office; and a second copy, of like scale and dimensions, has just been prepared for exhibition in the National Museum. The enlargement was effected by photographing the base up to the required scale and transferring the geology by hand.

It is proposed to issue, at an early date, a separate edition of the map in two impressions, one printed in the colors of the Fifth Annual Report edition and the other in the colors of a proposed color scheme, together with (1) an explanatory text relating thereto, (2) the experimental map described in a succeeding paragraph, and (3) an exposé of the cartographic scheme of the the Survey in the form of a bulletin.

The local map.—The geologic map of New York, Pennsylvania, and New Jersey, described in a preceding report, was completed in time for exhibition before the American Association for the Advancement of Science at Philadelphia in September last.

Unfortunately it was found, on attempting to delineate the geology of the three States, that our knowledge of the taxonomic and structural relations and the geographic distribution of certain formations is too meager to warrant final cartography of a considerable portion of New York and some contiguous parts of Pennsylvania. It has accordingly been decided to defer publication of the map until additional data shall have been accumulated.

Meantime, the manuscript copy of the map (scale, 6 miles = 1 in., or 1: 380160; dimensions, 6 feet 6 inches × 6 feet 2 inches) has been found convenient for office use; and it serves one of the purposes of its construction by illustrating the applicability of your cartographic scheme to the representation of minor geologic divisions on large scale maps as satisfactorily as can be done by any hand colored map.

The experimental map.— One of the principal functions of the United States Geological Survey, as defined by the law instituting it, is the preparation of a geologic map of the United States, which, as the language of the law implies, shall be of such scale and characterized by such colors or other conventions as may be required in the delineation of the structure of the entire region. In order to facilitate selection of the most suitable scale and conventional signs for such purpose, and at the same time develop a cartographic scheme which it is hoped may prove worthy of international adoption, it was decided over a year ago to prepare a map upon which different color schemes might be tested, and the local map already described was that first selected for the purpose.

When it was found inexpedient to print the map of the three States it became necessary to select some tract in which geologic structure and relation are typically exhibited for use in testing different cartographic schemes. A tract in northeastern Pennsylvania, southeastern New York, and northern New Jersey (lat. 40° 30′ to 41° 22′, long. 73° 30′ to 78° 30′; 60 by 255 miles) was finally chosen for this purpose. Within this tract are comprehended (1) undoubted Archæan terranes, (2) crystalline rock masses probably representing metamorphosed Paleozoic formations, (3) an extended series of unaltered Paleozoic formations representing all the groups of that system, (4) the two groups of the Mesozoic system, of which one is divisible into several formations, (5) several Cenozoic formations, (6) intrusives, in the two forms of dikes and sheets, and (7) superficial deposits of both immediate and remote derivation and of variable thickness and importance. The rock masses are of various thicknesses and variously affected by fracture, tilting, and corrugation, and in consequence the terranes are of width ranging from the narrowest zones representable cartographically to 25 miles; the altitudes of the little-disturbed terranes are various, and they are consequently variously dissected and geographically modified by erosion; most of the area has been so carefully studied that the identity of the rock masses has been finally established, and in all other respects the tract appears suitable for the purpose.

The preparation of a base map of the region was commenced in April, and although the work has been delayed upon it by other duties it approaches completion. The geologic data have been assembled and can be rapidly transferred when the drawing is finished.

It is proposed to lithograph this map and issue it in connection with the bulletin already mentioned at the earliest possible date, probably in time for the session of the Congrès Géologique International at Berlin in October next.

The geologic map of New York.—In pursuance of your oral instructions of November 20 last, I proceeded to Albany to assist the State geologist of New York, Prof. James Hall, in constructing a geologic map of that State.

It was supposed, when the preparation of this map was suggested, that data from which an accurate geologic map of the entire State might be readily compiled existed in the office of the State geologist, but it was soon found that, though of great value, these data were inadequate. They were accordingly supplemented by different means, and the record of additional data was elaborated in a report designed to accompany the map.

All possible information relating to the geologic structure and topographic configuration of the State was collected by correspondence and personal conference with citizens of the Stare and other gentlemen; and it is desirable to acknowledge their valuable contributions to the map more fully than can be done in its legend. Like information was obtained by research in the official and unofficial literature of the State, and to facilitate the work of future students a bibliography of this literature was prepared.

In order to extend the geologic conventions over as much of the State as possible it was deemed expedient to carefully examine certain typical localities which promised to afford keys to the structure of considerable areas. Accordingly, notwithstanding the lateness of the season, field investigations were undertaken by Professor Hall and myself at Saratoga Springs and in the dislocated region of the Mohawk. These investigations yielded results not only immediately serviceable in the preparation of the map, but of such value to geologic science as to warrant independent publication; and some time has been spent in preparing text and illustrations relating to these interesting geologic regions for publication in the report designed to accompany the map, and perhaps elsewhere.

Although the entire area of the State was geologically mapped in 1842 and again in 1844, it was found, after collating the records, that considerable portions of New York have never been explored geologically; and, in accordance with the conviction that geologic science may be best promoted and its utilitarian end best subserved by avoiding pretense to greater knowledge than is actually possessed, it was decided to leave these areas uncolored. Justification for incomplete cartography of a region previously mapped in entirety demands a demonstration of the untrustworthiness of the earlier cartography. Accordingly, the earlier maps and the published records upon which they were based were critically reviewed, with the purpose of showing that, while their accuracy in detail was equal to the requirements of the times and the state of geologic science then obtaining, it falls short of the more refined standards of to-day.

The report embracing these several treatises will form a considerable volume, but it is believed to be a necessary contribution to the scientific literature of a State classic in American geology.

The map is drawn to scale of 6 miles to an inch. It was completed in January, and a hand-colored copy, reduced to a scale of 8 miles to an inch, was soon after communicated to Professor Hall for temporary use. A smaller copy was also prepared for the use of this office.

Since there is not within reach of the working geologist a map of New York suitable for use in the field, it is proposed to compile and lithograph a base which shall not only serve for the present map, but form a convenient working map for the geologists employed in rectifying and extending the older surveys and eventually serve as a basis for a complete geologic map of the State.

The data for this base have been assembled, and it will be drawn as soon as the publication of the map is officially ordered.

Thesaurus of American formations.—By reason of the pressure of other duties, work upon the thesaurus (which was fully described in the report of last year) was suspended early in the present year. It will be resumed at an early date.

The geologic sketch of Texas, etc.—The geologic map of Texas, Indian Territory, Arkansas, and Louisiana, which this sketch is designed to illustrate, has been in readiness for the engraver for a year; and the text, exclusive of that containing the bibliography, is nearly ready for the printer.

Since the geographic work of this Survey has already been extended into the region covered by the map and geologic investigation must shortly be instituted there, it has been deemed wise to supplement the sketch by an exhaustive geologic bibliography of these States. The plan adopted contemplates a title bibliography, arranged, *first*, chronologically and, *secondly*, alphabetically by authors, with annotations indicating the scope and value of treatises (1) not readily accessible, (2) insufficiently described by their titles, (3) only referring incidentally to the geology of the region, or (4) for other reasons of little value to the general student.

Several hundred titles have been assembled and annotated.

The history of American State surveys.—Recent inquiries by the United States Government concerning foreign scientific surveys have demonstrated the desirability of recording in permanent and accessible form all available data relating to the organization, administration, cost, and material results of geologic, geodetic, geographic, mineralogic, agricultural, natural history, and other scientific surveys officially instituted at various times by the several States of the Union; and the necessity for immediate action in the collection of such is manifest, since much valuable information, particularly details of administration and cost, has never been published, but exists only in the memory of men, in private records, and in public records liable to become destroyed or forgotten with the decadence of the present generation.

Accordingly, by your direction, and with your constant co-operation, I have undertaken to collect material for a history of American State surveys, with a view of compiling and publishing it at the earliest possible date. The plan adopted is to invite gentlemen specially familiar with the scientific surveys of particular States or larger regions to prepare detailed historical sketches of such surveys, to be utilized in the compilation of the general history.

Correspondence in relation to the matter was opened April 15, 1885, and the responses thus far received have been most encouraging. Up to this date only six satisfactory sketches of different surveys have been communicated to this office; but histories of nearly all of the other surveys officially instituted in this country have already been promised.

FIELD WORK.

Investigations in the District of Columbia.—The investigation of the superficial and other formations and the fluviatile and littoral terraces of the District of Columbia and contiguous territory, commenced two years ago, has been prosecuted as energetically as the pressure of other duties and the imperfection of existing maps permitted.

By reason of the necessity for concentrating a considerable portion of the topographic force of the Survey in Massachusetts, at the beginning of the year, Mr. Sumner H. Bodfish, who had been detailed to survey and map the region about the National Capital, was transferred to that field, and the work here was suspended; and since there is not in existence a topographic map of the region sufficiently detailed and accurate for use even in reconnaissance (for the interrelation of terraces and deposits cannot be inferred until the terraces have been at least partially co-ordinated), the geologic work has thereby been greatly retarded. The topographic survey thus suspended in July last was, however, resumed in May, under the direction of the Chief Geographer of the Survey. The completion of the survey and the preparation of the map have been intrusted to Mr. John D. Hoffman and the plan for the map has been modified. It is now proposed to construct it in two sheets, bounded, respectively, by latitude 38° 45′ to 39°, by longitude 76° 45′ to 77°, and latitude 38° 45′ to 39°, by longitude 77° to 77° 15′, on a scale of 1 : 63360, with 20-foot contours. Mr. Hoffman has had a party in the field since May, and, in addition, has spent considerable time in compiling existing data and transferring the results of Mr. Bodfish's work to his own field sheets.

Pending completion of the topographic map, the preliminary reconnaissance has been extended beyond the limits of the District in all directions; the various sewer, reservoir, tunnel, street, and other excavations of the District, in which phenomena of geologic significance are revealed, have been examined from time to time, a number of photographs and drawings of exposures have been made, and a collection of silicified and lignitized wood from the Potomac formations has been brought together with a view to generic identification by microscopic examination.

Investigations in the Potomac, Cheat, Monongahela, and Ohio Valleys.—The terraces in the District of Columbia, which are in part fluviatile and in part littoral, are indicative of orogenic movements, presumably extending into and perhaps culminating in the Appalachians; and terraces in the valleys of the upper Potomac and its tributaries, and in the Ohio and certain of its affluents, originating on the western slope of the Appalachians, have been described by W. M. Fontaine, J. F. Campbell, J. J. Stevenson, J. P. Lesley, G. F. Wright, and others, who have advanced different hypotheses as to their origin.

Comparative study of these terraces promised to yield valuable results; and accordingly a trip up the Potomac River from Washington to its source in Highland County, Virginia, across the Alleghany Mountains to the headwaters of the Cheat River, down the Dry Fork and main Cheat to its confluence with the Monongahela, down that stream to its union with the Alleghany at Pittsburgh, and thence down the Ohio to Wheeling, was performed during the period from September 17 to October 10 last. Since, in the pursuit of geologic clews, it was desirable to traverse cultivated fields, virgin forests, pathless gorges, and untrodden mountain crests, alike impassable for vehicles or even animals, the entire journey was performed on foot.

Though comparative study of the terraces was the primary object of this journey, the correlation of the rock formations of the District of Columbia with those of the better known Appalachian region was a secondary object.

Between the known newer Mesozoic terranes of the District of Columbia and the known Paleozoic terranes in and west of the Blue Ridge lies a broad zone of crystalline rocks (partly covered by older Mesozoic sandstones, shales, and conglomerates), whose position in the geologic column has not been determined. The relations of these rocks to the Paleozoics in the Blue Ridge are obscure; and since they were not ascertained during the first trip through the region, the most important localities were twice revisited, once in company with Prof. W. O. Crosby, of the Massachusetts Institute of Technology, and once with Prof. George H. Williams, of Johns Hopkins University. Since no fossils were found about the locus of passage from known clastics to crystallines of doubtful genesis, a series of rock specimens was collected in the hope that by microscopic examination they might be made to yield evidence of the relations of the rock masses.

Twenty-five slips have been prepared from these specimens. They will be examined at an early date by Professor Williams.

Investigations in Wisconsin and Iowa.—In prosecuting a geologic survey of northeastern Iowa, at private cost, some years ago, certain lines of investigation were not pursued to their limits, partly because the area involved extended into other States in which official surveys were in progress. One of these lines of investigation related to the distribution and other phenomena of the loess in the driftless area of Wisconsin. Since this amateur survey was brought to an end, the State survey of Wisconsin has been completed and the final reports have been published; and when the former State geologist, Prof. T. C. Chamberlin, Geologist United States Geological Survey, courteously offered to pilot me through the driftless area and contiguous portions of Wisconsin, I gladly availed myself of his kindness. Subsequently, in company with the same gentleman, I reviewed some of my own work in Eastern Iowa. These tasks occupied the latter part of October and early November. The results will be incorporated in a memoir on the superficial geology of northeastern Iowa, the material for which has been in hand for some years.

Investigations in New York.—During the course of preparation of the geological map of New York it became necessary, as already intimated, to minutely examine the geologically complex area about Saratoga Springs, and the equally complex dislocated region of the Mohawk Valley; and in the latter part of December Professor Hall and myself visited these regions and collected data for geologic maps, sections, and stereograms, exhibiting their structure in detail. The proposed disposition of this material has already been noted.

Investigations in Kansas.—The salient phenomena of the Cenozoic and Mesozoic formations typically developed and well exposed in the mountainous portions of Colorado have been brought out by scientific surveys in that State. But little is yet known of the physical and paleontologic character of these formations in their easternmost extension (particularly in Kansas and Indian Territory), of their relations to the Paleozoic formations of the Mississippi Valley, or of the geography of the periods during which they were deposited.

As a first step in the process of filling this hiatus, I have, at your suggestion, employed Mr. Robert Hay, of Junction City, Kansas, to construct a section through Southern Kansas and Colorado, along the line of the sixth standard parallel south (not far from latitude 37° 20′), from the previously studied Carboniferous terranes of eastern Kansas to the region of typically developed Cretaceous formations in Colorado.

Mr. Hay took the field at Wichita, Kansas, on the 15th instant, and has already reported progress.

It is but just to you, and a pleasure to me, to add that many of my duties have brought me into so intimate association with yourself, and that I have so frequently availed myself of your casual suggestions as well as your specific instructions, that it is difficult in some cases to discriminate between my own work and that which might more properly be credited to you.

I have the honor to be, sir, very respectfully, your obedient servant,

W J McGEE,
Geologist.

Hon. J. W. POWELL,
Director United States Geological Survey, Washington, D. C.

REPORT OF MR. T. C. CHAMBERLIN.

UNITED STATES GEOLOGICAL SURVEY,
GLACIAL DIVISION,
Beloit, Wisconsin, July 2, 1885.

SIR: I have the honor to present herewith a report of operations of the glacial division for the year ending June 30, 1885.

The general plan of administration has not departed essentially from that heretofore indicated, though several special lines of investigation have been added. Among these are monographic studies upon the drumlins, the osars, and upon bowlder trains. The chemical study of the drift, which I regard as a most neglected subject, has become fairly inaugurated. Extensive sampling has been made in various parts of the field with a view to securing a basis for comparisons and generalizations that shall not be obnoxious to the charge of insufficient breadth and comprehensiveness. The determinations thus far made have been of the simpler, but yet significant kinds. The presence of calcic and magnesic carbonates in notable quantities in the drift clays is perhaps the most easily detectable and most widely prevalent index of their mechanical origin, in distinction from an origin through secular disintegration. The previous investigations of the Survey, particularly those in charge of Professor Salisbury, have shown the practical absence of these carbonates from the residuary earths, even when derived from limestones. Their prevalence in glacial clays becomes, therefore, diagnostic, subject, to be sure, to certain qualifications which, however, have no great application. Some thousands of simple acid tests in the field, a considerable number of partial quantitative determinations, and a few complete analyses have been made.

Microscopic work has also been inaugurated, but has thus far been chiefly confined to the determination of the character of the assortment of particles which the several deposits present, and particularly to the discrimination between residuary earths, glacial clays, and the loess. Results that promise to be important, when fully verified, have been attained.

The work of Prof. J. E. Todd during the year was a direct continuation of that upon which he had been engaged for the two preceding years, namely, the tracing out of the morainic systems of Southern Dakota and the detailed determination of the relations of these to associated formations and to the topography and drainage systems of the region. It was deemed advisable that he should spend the field season in the study of the lower portion of the Territory lying south of 44° 30′ north latitude, and that he should gather his results into a bulletin to be completed at an early day, leaving the more northerly portion of the field for subsequent investigation.

He took the field on August 4 and continued there until October 9. The larger portion of this time was consumed in an examination of a belt lying adjacent to the Missouri River and reaching from about 44° north latitude around to the Big Sioux River, but considerable time was devoted to supplementary examinations in other parts of the area and in adjacent parts of Nebraska. The leading results of the year's investigation are the following:

(1) The establishment of the former existence of a large glacial lake north of and around the Bijou Hills.

(2) The tracing, with considerable definiteness, of two series of terraces along the Missouri and Big Sioux Rivers.

(3) The definite location of the outer or principal moraine from Kimball southward and eastward and then northward around to Wall Lake, and of the second moraine from Canistoga to Mitchell.

(4) Further exploration of the loess which lies around the terminal portion of the later drift, embracing the addition of several important features concerning it. Among these may be noted (*a*) the tracing of several broad, shallow, sandy northwest-southeast valleys across the divide between the northward-flowing tributaries of the Missouri, on the one hand, and the streams which flow in a southerly direction on the other; (*b*) further and more specific data respecting the eroded surface of the drift under the loess; and (*c*) additional evidence indicating the recent tilting of the loess surface toward the east.

(5) The discovery of Pliocene beds (Loup River group of Hayden) as far east as Frankfort, Nebraska.

(6) The detection of Dakota sandstone beds along the James River, above Milltown, on Enemy Creek, and on the Fire Steel, as far as 6 miles above Mitchell.

(7) The discovery of Niobrara chalkstone near Canton and north of Mitchell, near the Dakota beds above mentioned.

(8) The discovery of a quite extensive bed of siliceous flour, largely a hydrous silicate of alumina, just below the drift, east of the lower curve of the Bazile River. It seems exactly similar to certain beds upon the Republican River which have been called volcanic ash.

(9) A thin vein of coal near the ferry-landing at Ponca, identified as belonging to the upper portion of the Dakota beds.

Professor Todd took about sixty photographs and made representative collections. He was assisted in the field by Mr. L. B. Avery and Mr. E. W. Brooks.

Prof. R. D. Salisbury took the field on the 11th of July, resuming his investigations upon the drift phenomena adjacent to the driftless area of the upper Mississippi Valley. The special subjects of his investigation during July and August, were the character and distribution of pebbly drift along the west border of the region, in the vicinity of the Mississippi, and westward to the continuous drift-sheets of Iowa and Minnesota, and the not less remarkable vanishing edge of the loess deposit. This pebbly belt was found to be limited on the east to the vicinity of the Mississippi River, though occasionally represented by pebbles upon the eastern side, being thus shown to terminate in anomalous topographic situations. It was likewise determined that the loess terminates in a vague, almost undefinable, edge on the east side of the Mississippi, within from 10 to 15 miles of it. The determination was rendered difficult by the modification of the attenuated border of the loess, through its admixture with secondary deposits of residuary earths, and by the erosion which it has suffered since its deposition, but it was satisfactorily demonstrated that the deposit not only does not cover the driftless area in general, but that it does not even cover large areas of less altitude than that which it occupies, illustrating again the anomalous attitudes which this formation assumes. The two determinations supplement and corroborate each other, and indicate that conditions suitable for the distribution and deposition of these attenuated formations were prevalent along the western border of the driftless area but not over its central and eastern portions.

The flood-plain deposits of those valleys which lead up to the border of the newer drift, whence the deposits originated, were also subjects of study, as well as the slack-water deposits of tributaries caused by the filling of primaries by glacial floods. In the latter portion of the year. Professor Salisbury entered upon the microscopic study of the residuary earths, loess, and glacial clays. Illustrative specimens and photographs were taken throughout the field work.

Professor G. F. Wright became associated with the division at the beginning of the fiscal year and devoted the month of July to determining the southern limit of drift through the State of Illinois, which was found to enter the State near Phillipstown, White County, and to bear in a general southwest direction through Gallatin, Saline, and Williamson Counties, whence it turns northwesterly and extends through Jackson, Randolph, and Monroe Counties, coinciding with the east bank of the Mississippi Valley up to the vicinity of Saint Louis. Nowhere in this region are the glacial deposits thrown into ridges and hills, as is so usually true of the border of the drift of the later epoch. Loess was found to conceal the border to a greater or less extent. Striated surfaces were discovered 2 or 3 miles south of Carbondale, in Williamson County, bearing south from 10° to 15° east, and in Jackson County bearing south 5° west.

The earlier part of August was spent in the study of terraces in the western portion of Pennsylvania, embracing those of the Monongahela and Alleghany Rivers and Beaver and Chartier's Creeks, as well as of the Ohio.

The latter part of August and the earlier half of September were spent in Hamilton and Butler Counties, Ohio; Campbell, Kenton, Boone, Gallatin, and Trimble Counties, Kentucky; and Jefferson and Switzerland Counties, Indiana, adding to previous data respecting the border phenomena of the drift. An examination was made of the vegetal beds of Butler County, photographs of which were taken showing the nature of the deposits and the situation of the fossil wood in them, specimens of which were collected.

During the month of June, 1885, Professor Wright supplemented his former investigations in Hamilton, Clermont, Brown, Pike, and Ross Counties, Ohio, and made a study of Teaze's Valley through its whole length in Putnam and Cabell Counties, West Virginia, and its extension in Boyd and Greenup Counties, Kentucky.

Seventy photographs were taken during the year and 175 samples of earth were collected from different portions of the territory visited. Professor Wright was assisted by Mr. W. B. Metcalf during a portion of the field season and in the laboratory and by Mr. J. P. MacLean in the study of the vegetal deposits of Butler County. Mr. Metcalf made a number of determinations of the carbonates in pursuance of the general plan of chemical investigation above alluded to.

Prof. George H. Stone, of Colorado, became associated with the glacial division at the opening of the fiscal year, and was engaged from the early part of July until the 3d of September in the study of the osar systems of Maine, to which he had previously devoted much labor as an amateur. His work during the summer consisted in the further tracing out of the osar systems which had become known to him through previous investigations and their more complete investigation and mapping. To this he added the discovery of some new systems and the collection of a large mass of data bearing upon the specific characteristics of these remarkable formations. Incidental to this leading line of investigation, he made numerous observations upon striæ and other evidences of glacial movement. Among these he found evidences which have been very commonly interpreted as indicating local glaciation, but which, on more complete and critical investigation, may prove to be only local deflections of the currents of the vanishing ice sheet. He also observed transverse belts of special drift accumulations that probably belong to the category of terminal moraines, though no continuous system was discerned.

On the 1st of June, 1885, Professor Stone resumed his investigations in the field, and during the month has been engaged in the study of the glacial phenomena of the islands of the coast of Maine.

During the year, Mr. W. M. Davis, of Harvard University, has become associated with the glacial division and has undertaken the special study of drumlins and certain selected subjects of monographic study. His other engagements have not permitted him to devote much time to the Survey, up to the present date, and his investigations can only be said to have begun. Besides observations in the vicinity of Boston, he has commenced the examination of the belt of drumlins that stretches from the vicinity of Brookfield and Spencer, Massachusetts, toward Pomfret, Connecticut, and has already determined its lateral limits at several points. He found the drumlins of the belt about Spencer to stand on a base elevated 1,200 feet above the sea but to present all the peculiarities of those seen at lower levels.

In connection with this work, he has recently been engaged in the collection of data for a map illustrative of the glaciation of Mount Monadnock, the leading theme of study being the deflections of striæ from their usual trend, determined by the topographic features of the mountain. He has already observed a variation from S. 3° W. to S. 80° E., a range of almost 90°.

Mr. I. M. Buell was employed, under my immediate supervision, during portions of July, August, and September, 1884, and May and June, 1885, in tracing out and mapping the bowlder trains of Central Wisconsin, which originate from the isolated knobs of quartzite and quartz porphyry that there protrude through the Paleozoic formations. The leading purposes of the investigation were the determination of the amount of glacial abrasion which the knobs suffered, which it was sought to estimate both by a direct study of the modifications of the forms of the knobs, when compared with those in the adjacent non-glaciated area, and by a careful estimate of the amount of material carried away and distributed in the bowlders that constitute the trains. It was further hoped to secure approximate data respecting the amount of abrasion which the bowlders themselves suffered in the course of their transportation. The divergence of glacial currents, as indicated by the progressive spreading of the train, and the distance of transportation, as determined by its length, were among the results anticipated. A very considerable mass of specific data was collected, but the investigation is as yet incomplete. Incidentally, some of the drumlins of the region became subjects of study, as they lay directly in the path of the trains from the Portland and Waterloo quartzites. The distribution of bowlders over and through these, furnishes data of some significance in the study of these forms.

In the middle of September, under my immediate supervision, Mr. D. W. Mead undertook the mapping of the glacial flood plains and the terrace systems of the Chippewa Valley of Wisconsin. There originated from the exterior margin of the outer terminal moraine of the later epoch extensive gravel plains, which gathered into the main valleys, and, joining, formed a sand and gravel stream which filled the ancient Chippewa Valley to upwards of 100 feet in depth, converting it into a broad plain. Out of this a fine system of terraces was subsequently carved by the streams. It was sought to ascertain by a study of these what light could be thrown upon the orographic movements of the region, as well as the special conditions which presided over the development of the terraces. His work was concluded in November, but I have been unable as yet to fully discuss the results.

My own time during the months of July, August, and September was chiefly occupied in the study of the several problems of the driftless region, in association with Professor Salisbury. In the latter part of September, I spent a few days in inaugurating the work upon the flood plains and terraces of the Chippewa Valley and in an examination of some of the problematic phenomena connected with the older drift of that region.

I subsequently made a reconnaissance along the lines of the Chicago, Milwaukee, Saint Paul and Omaha Railroad in Northwestern Wisconsin, which have recently opened up a territory previously rendered inaccessible to satisfactory investigations because concealed by an extensive forest, but in which the drift is now finely exposed by numerous fresh, deep cuts. For 40 miles along the line from Chippewa Falls to Superior City there is a scarcely interrupted succession of cuts through morainic and kame-like hills and ridges, showing a great variety of gradations, from till to almost pure sand, embracing wide variations in kind and degree of stratification, from almost inextricable confusion to perfect assortment. While the obliquity of the line somewhat increases the apparent width of the belt, it still shows a magnitude of kame-like accumulations that are altogether fatal, in the very element of magnitude, to some current hypotheses concerning the origin of such deposits. The line from Ashland to Saint Paul traverses the belt in a more longitudinal direction and more largely follows river flood plains, but yet displays an extended and very striking series of sections. Brief notes were made on over one hundred of these sections. In the interpretation of kame-like accumulations such grand belts as these, and those which are elsewhere displayed in association with the great morainic tracts described in the Third Annual Report, are features of prime significance.

In October, a short time was given to a re-examination of a portion of the southeastern border of the driftless area in the hope of finally laying at rest all skepticism concerning the absence of loess from that region, notwithstanding the fact of its higher elevation on the western side. One hundred and fifty railroad cuts, in situations favorable for the retention of loess, or any other Quaternary deposit that might be supposed to have overlain the region, added to the re-exploration of considerable territory along the border and on the edge of the drift, appear to give thoroughly satisfactory evidence that the submergence of the region, which has been maintained by several writers, was not a verity.

A little later, in connection with Mr. McGee, I visited several typical regions in Wisconsin and Iowa for the purpose of mutual comparison of observations and interpretations and the better correlation of our studies upon phenomena, which, though closely adjacent geographically, are, I think we were both convinced, somewhat widely differentiated in specific character.

In November and December I made a somewhat extensive reconnaissance in the southwest and south, for the purpose of bringing into sharper definition the problems of the plains and of the lower Mississippi Valley in their relations to the drift phenomena of the northern region. This reconnaissance extended as far west as Denver and as far south as Dallas and Vicksburg. It involved some studies in southern Iowa, northern Missouri, and a zigzagging of northeastern Kansas along the line of the border of the loess and of the drift; more cursory observations on the plains and upon the flood drift of the Rocky Mountains, a reconnaissance of the plain region south of the old Pliocene lake, in the pursuit of ancient drainage features; and some brief studies of the loess and Orange sand about Vicksburg and Jackson, Mississippi, Memphis and Humboldt, Tennessee, and Columbus, Kentucky. The results of such a reconnaissance are scarcely worthy of record here, except a few that are mainly dependent upon previous and less brief studies.

1. In harmony with all previous observations in the interior basin, I found in Nebraska, Kansas, and Missouri no evidence of morainic ridging on the border of the drift, and it may be safely asserted that no such morainic aggregation exists, except as a local development, as is the case in south central Indiana, noted in the Third Annual Report of the United States Geological Survey, page 333. 2. I could not find in the gravels of the so-called Orange sand at any point examined, not even as near the drift as Columbus, Kentucky, evidences of glacial derivation. While it would be premature to express an opinion, there is ground for grave doubt whether the Orange sand, even in these most typical localities, belongs to the glacial period at all. The current doctrine that it is of the Champlain epoch, I am convinced, is not only wholly untenable, but is about as far astray as it is possible to be within the range of the Quaternary period. 3. It seems to me almost equally certain that the loess deposits of the Lower Mississippi much antedate the Champlain epoch. 4. The distribution of the loess and of certain plain-surface-drifts, together with numerous Quaternary drainage features, seems only explicable on the assumption of changed attitudes of the crust, and appears to open up broadly on an observational basis the question of orographic differential movements during and since the Quaternary period.

All members of the division have given a portion of their time during the winter months to the elaboration of the data secured in the field and the preparation of bulletins which will embrace the results of their investigations. Several of these bulletins are in an advanced state of preparation.

I am happy to announce that at the beginning of the coming fiscal year two of our most experienced glacialists will undertake investigations in association with the division — Prof. N. S. Shaler, of Harvard University, and Mr. Warren Upham, recently of the Minnesota Geological Survey. The former will attack some of the special drift problems of New England and the latter will continue his well known investigations on the extinct Lake Agassiz.

Very respectfully, your obedient servant,

T. C. CHAMBERLIN.

Hon. J. W. POWELL,
Director United States Geological Survey, Washington, D. C.

REPORT OF PROF. R. D. IRVING.

UNITED STATES GEOLOGICAL SURVEY,
LAKE SUPERIOR DIVISION,
Madison, Wisconsin, June 30, 1885.

SIR: I have the honor to submit the following report of the operations of the division of the Survey under my charge for the year ending June 30, 1885.

The work of this division is a general investigation of those formations of the Northwestern States which underlie the basal fossiliferous sandstone of the Mississippi Valley, this sandstone being generally taken to be the geological equivalent of the Potsdam sandstone of New York. The rock systems under study include the enormously thick and complex formations which have been called the Laurentian and Huronian; and also the Keweenaw series of the Lake Superior region. In the Fifth Annual Report of the Survey (pp. 24–28, 175–242) I have given a general account of my plan of operations and progress to date, as also a general preliminary geological map of the Northwest. Reference to that map and the accompanying report will aid in the understanding of the following account of operations for the year just closed.

FIELD WORK.

In addition to what I have done in the field myself during the year, independent parties have been led by Assistant Geologists Hall, Merriam, Chauvenet, and Van Hise.

Professor Hall's party.—Professor Hall, with one assistant, Mr. J. E. Manchester, was occupied from the 1st of July to early September in a study of the gneissic formation of the Minnesota Valley from New Ulm to Big Stone Lake. The exposures along the valley are very numerous though confined mainly to the wide river bottoms, and Professor Hall has made a very thorough study of all, collecting a large series of specimens which are now under microscopic study.

Mr. Merriam's party.—Mr. Merriam was occupied during August, September, and October in an examination of an extended region in the vicinity of Vermillion Lake and to the north and east of it, the area examined overlapping on the east that studied by Mr. Chauvenet during the same and several previous seasons and extending along the natural boundary line as far as the western end of Crooked Lake. The immense number of very irregularly outlined lakes which stud the region offer to the geologist, with their connecting water courses, an unusually favorable opportunity for work in a country which would otherwise be equal to any other in the United States in difficulty of penetration. The lakes not only afford the means of getting readily from place to place, but they make also frequent bold and cliffy exposures of the rocks along their shores and give an opportunity to study the various rock belts, not merely in the direction of the strike, but also in directions transverse to it. These lakes are of yet further advantage, in that, having been "meandered" by the United States surveyors, they furnish us with numerous surveyed lines fixed with reasonable accuracy, within the sections, the interiors of which are left entirely unsurveyed in regions without large lakes or rivers.

After making some studies of the country in the immediate vicinity of Vermillion Lake, Mr. Merriam started from Two Rivers, situated at about the middle of the south side of that lake, on the 14th of August, with a party consisting, besides himself, of one woodsman and two Indian canoemen, disposed in two two-fathom canoes. From Two Rivers the course of the party lay north of east through Vermillion, Mud, Burnt Side, and Long Lakes to Falls Lake in the northern part of T. 63, R. 11 W.; and from here southward through Farm, White Iron, and Birch Lakes and the Metawanga River to the southern part of T. 60, R. 12 W. Leaving his canoes here, Mr. Merriam examined the flat lying, iron-bearing beds of the Animikie series as far eastward as Iron Lake, in Sec. 13, T. 60, R. 13 W. These beds lie on the south side of the Mesabe granite range and a section has thus been obtained all across from the vertically placed iron-bearing rocks of the Vermillion Lake basin to the flat-lying Animikie beds. The Metawanga River was next followed downward to Birch Lake, from the western end of which lake, in T. 61, R. 13 W., a portage was made westward into Bear Island Lake, where fine displays are to be seen of the granite and gneiss that separates the flat Animikie rocks, just mentioned, from the Vermillion Lake schists. Birch Lake was next examined in detail on both sides, after which the party returned to Farm Lake. From here a long series of lakes, with short intervening portages, was followed eastward through a country which, in the main, is not yet subdivided by the Land Office, for a distance of about 30 miles, or about as far as the middle part of T. 63, R. 6 W. (unsurveyed), thus overlapping Mr. Chauvenet's work by some few miles. In this long eastern stretch, since the formations of the region have a general northeasterly course, a second cross-section was obtained from the Vermillion Lake iron-bearing schists to the gabbros at the base of the Keweenaw series. Turning now, Mr. Merriam retraced his course for about 20 miles to T. 63, R. 9 W. (unsurveyed), and traveled thence northward through Moose and Wind lakes in T. 64, R. 9 W., into Basswood Lake, on the national boundary line, where a second connection with Mr. Chauvenet's work was made. The national boundary line was now followed northwestward through a series of small lakes with intervening rapids to Crooked Lake, and through this lake to Iron Lake, in the northeastern part of T. 66, R. 13 W., which was the furthest point reached.

The return journey was made through Crooked, Basswood, Falls, Long, Burnt Side, and Mud Lakes to Vermillion Lake, Mr. Merriam examining in detail such points on these lakes as had not been studied before. Vermillion Lake was reached on the 6th of October. From this date to the 23d of October the time was devoted to a minute examination of the numerous rock belts exposed along the many extended ramifications of Vermillion Lake, and to making a third detailed section from the Vermillion Lake schists to the gabbros south of the Mesabi Range, in this case along the line of the recently completed Duluth and Iron Range Railroad. This work finished, Mr. Merriam's intention was to return to the vicinity of Birch Lake for further studies; but cold weather setting in and the lakes beginning to freeze, this work had to be abandoned until another season. Without counting anything but the main lines of his course, it appears that Mr. Merriam traveled in his canoes a distance of between three and four hundred miles, besides making various lateral excursions on foot. Although subjected during the first part of the time to much inconvenience on account of heavy rains, Mr. Merriam had on the whole a most successful season in this region, having covered a far larger area than was hoped for, most of which had never been before examined by any geologist, and having brought back a most admirable series of notes and a collection of over 500 specimens. Allusion is made further on to the results thus far obtained by ourselves and other geologists in northern Minnesota.

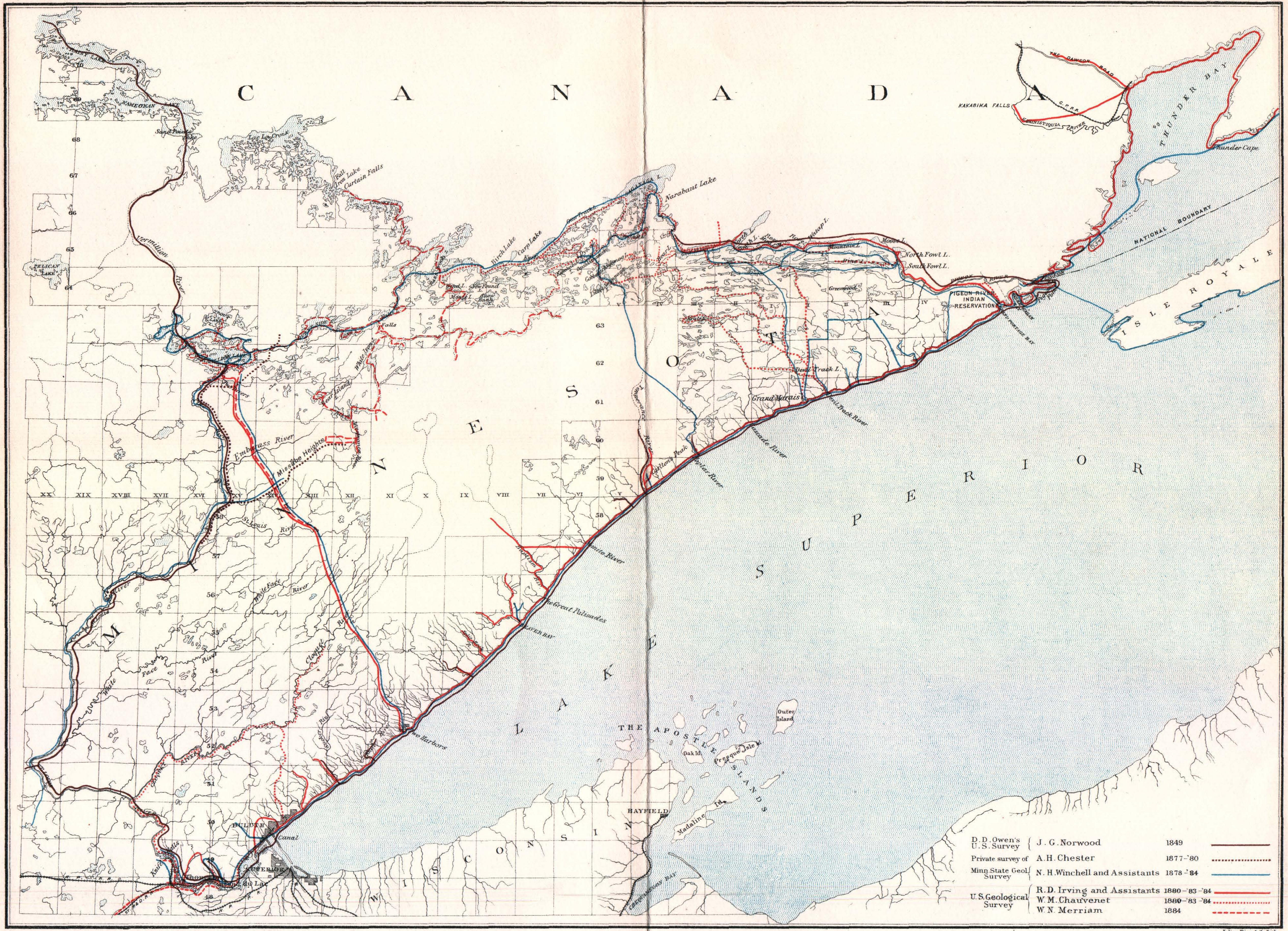
Mr. Merriam returned from the Vermillion Lake country to Madison on the 25th of October. Two days later he left, under my instructions, for Keweenaw Point, for the purpose of making some detailed measurements of certain places which had been examined by myself in company with Professor Chamberlin, as explained below, and in this work he was occupied until the 5th of November.

During the month of June Mr. Merriam has been in the field in central and western Minnesota, with the object of restoring for that region the most important specimens and photographs lost at the time of the burning of my office in the State University at Madison, as below described.

Mr. Chauvenet's party.—During four weeks in the latter half of August and the first half of September Mr. Chauvenet was occupied in a continuation of the examinations begun by him during the previous season in the region north of Grand Marais and along the national boundary line, particularly in the vicinity of Ogiskemanissi and Kekekabic Lakes, in T. 64, R. 4 W., and T. 64, R. 5 W. Mr. Chauvenet was instructed to choose his routes on different lines from those followed on previous years, so as to extend our knowledge of this region as far as possible. In accordance with these instructions, Mr. Chauvenet, leaving Grand Marais with four Indian packers and two canoes, took a northerly course through R. 1 E., to Round Lake in section 17, T. 64, R. 1 E., and thence through a series of lakes northwesterly to Moss Lake in the southwestern part of T. 65, R. 1 W. Gunflint Lake was next reached through several smaller lakes and through South and North Lakes on the national boundary. From the eastern end of Gunflint Lake a trip was taken to the northward on the Canadian side of the lake with the object of gaining further light as to the relations sustained by the cherty ferruginous beds of the Animikie series, which make so large a display about Gunflint and North Lakes, to the granites and vertically placed schists lying immediately to the north of them. The relations of the same two formations were next studied through the eastern part of T. 65, R. 4 W., beyond the western end of Gunflint Lake. A series of traverses was next made covering the whole of the south half of the township just named and the southeast quarter of the one lying just to the west, with the result of determining very satisfactorily the distribution of the granite, and of the green schist with which it is associated, and of the ferruginous rocks, gabbros, slates, etc., of the Animikie series, as well as the mutual structural relations of the several kinds of rock. The northern part of this township had already been studied during the previous year. From Bear Lake, in the southern part of T 65, R. 4 W., the party next made its way southwestward through a series of lakes to Little Saganaga Lake, in the western part of T. 64, R. 5 W. From here the same route was followed, as on a previous year, through Gobbemichigomog, Agamok, and Fox Lakes to Ogiskemanissi Lake, in T. 65, R. 6 W. A number of days were then spent about this lake and Kekekabic Lake, southwest from it, with the view of studying carefully the very peculiar and enormously thick conglomerate which is displayed along these lakes, important questions having been raised as to the relations of this conglomerate to the surrounding formations. Little Saganaga Lake lies entirely within the great gabbro formation which intervenes between the Animikie slates and the Keweenaw or copper-bearing series proper, the appearance being as if, in this vicinity, the gabbro formation entirely overlaps the Animikie so as to come against the folded slates on the north. To get further light on this matter, Mr. Chauvenet made a canoe trip southward from the western end of Kekekabic Lake through a series of large-sized lakes as far as the southern part of T. 63, R. 7 W., in which township he crossed the route followed by Mr. Merriam, as already stated. The result of the trip was to prove, as Mr. Merriam also independently did in his work further west, that the great gabbro formation, which forms so prominent a feature of the country north of Duluth and south of the Mesabe Iron Range, does here entirely overlap the Animikie formation. Returning now to the western end of Gunflint Lake, some further examinations were made in that vicinity, after which the party returned to Grand Marais by the same trail as followed on the outward course.

Accompanying this report is an outline map of the triangular area in Northeastern Minnesota lying between Lake Superior and the national boundary line and bounded on the west by the Vermillion and Saint Louis Rivers. On this map I have indicated by colored lines the courses taken by Dr. J. G. Norwood in 1847-'48; Prof. N. H. Winchell, of the Minnesota State survey, in the years 1878-'79; by myself in the seasons of 1880, 1883, and 1884; by Mr. Chauvenet in the same years, and by Mr. Merriam in 1884. Besides the examinations thus indicated I am not aware that any other geological work has been done in this very interesting region except what has been accomplished by Bigsby, Bell, Selwyn, and other Canadian geologists along the old canoe route which forms the national boundary line and northward from there in the British possessions. The earlier surveys—that is, those which preceded Professor Winchell's explorations—are of little value to us, having been almost entirely conducted before there were any surveyed lines in the region, so that the descriptions and locations are of the very vaguest character. Combining the results of these various explorations, we find ourselves able for the first time to reach an intelligent conception of this region—than which, it would be safe to say, no other area of equal size east of the Mississippi River makes more magnificent displays of the enormously thick formations which lie at the base of the geological column or offers a greater variety of rock kinds to the study of the geologist. Unfortunately, although largely subdivided into townships and sections, the region is still almost a complete wilderness, so that geological work in it is slow and expensive.

Professor Van Hise's party.—Professor Van Hise, accompanied by one woodsman and two packers, devoted the months of July and August to the study of that portion of the Penokee-Gogebic iron belt lying between the Montreal River and Lake Gogebic. As explained in my paper in the Fifth Annual Report (pp. 175-242), this work is a continuation into Michigan of that previously done by the Wisconsin survey in northern Wisconsin. Professor Van Hise's work in this district has been quite detailed, and his large collections of specimens having been studied microscopically a number of very interesting conclusions have been reached. It was our intention to present for publication before now without further work in the region an account of its geology. So important, however, is the region in its bearings upon the broadest questions in Lake Superior geology, such as the divisibility of the Archæan, the structure of the Lake Superior basin, the stratigraphy of the Huronian series, etc., that I have decided to attempt a general revision of the whole belt for the seventy miles between Lake Numakagon in Wisconsin and Lake Gogebic in Michigan during the season of 1885. I have been the more impelled to this decision by the recent entire destruction of the large Wisconsin Survey collections from this



MAP OF NORTH EASTERN MINNESOTA, SHOWING ROUTES OF GEOLOGICAL EXPLORATION, 1849-84.

Scale $\frac{1}{975,000}$ = 15.38 miles : 1 inch.

20 10 5 1 0 10 20 40 60 STAT. MILES

region. To the preparation of a satisfactory account of the region as a whole, these Wisconsin collections seemed quite necessary, and it is our plan in the revision to replace them so far as may be needed. In this work of revision Professor Van Hise is now already engaged, having taken the field June 24.

My own studies in the field during the year have included examinations of the gneissic series of the Minnesota Valley, in company with Professor Hall's party; of the region along the Saint Louis River, in the vicinity of Thompson, Minnesota; of the region about the iron mines of Vermillion Lake, in company with Mr. Merriam's party; of the country between Thunder Bay and the national boundary line, particularly along the Kaministiquia River, the exposures along which river, though on the Canadian side of the boundary line, are very important in furnishing a correct understanding of the region between the boundary and Lake Superior; and, in company with Prof. T. C. Chamberlin, of a portion of Keweenaw Point, where we made together a detailed study of the contact between the Keweenaw series and the so-called Eastern Sandstone. My field work in Minnesota was during the months of July and August; that on Keweenaw Point during the month of October.

OFFICE WORK.

Before describing the work accomplished in the office during the year, it will be necessary for me to allude to the disastrous fire by which the larger part of our records and specimens were lost on the night of the 1st of December, since this fire has profoundly affected the work of the remainder of the year, and will influence not a little that of the year just about to begin. By the courtesy of the authorities of the University of Wisconsin, the office work of my division of the Survey has been carried on in my office in the Science building of that institution, which building was totally destroyed on the night mentioned. Our offices being situated on the third floor from the ground it was not possible for us to save very much; but, chiefly through the activity of Professor Van Hise, we succeeded in securing most of the field notes pertaining to the present investigation and all but about 50 of 2,200 thin sections. Otherwise our records, specimens, instruments, camping material, etc., were almost wholly lost. Our collection of hand specimens had grown very large and represented all portions of the Archæan of the Northwest. Including, also, a collection of about 3,000 made by the Wisconsin survey, there were at my disposal, in the University building, about ten thousand rock specimens, chiefly derived from the Archæan formations I am now engaged in studying. Besides this loss, we have suffered severely in the loss of the series of notes, made chiefly by myself, covering about ten years' study in the Lake Superior and immediately adjoining region prior to the beginning of our present work. Mr. Merriam's field notes for his long and very successful trips made in Northeastern Minnesota in the summer of 1884 were entirely lost, so that this work will have to be almost wholly done again, little more remaining to us than his general knowledge of the distribution of the formations. In addition to these losses, we have lost between two and three hundred photographic negatives, taken all about the Lake Superior country; a very large and complete collection of maps illustrative of the region we are now studying; as also most of our instruments and camp equipage.

Lithological work.—The microscopic work of the year, in which I have been aided chiefly by Professor Van Hise, has included studies (1) of sections from the Gogebic-Huronian belt; (2) of sections representing the formations of Northeastern Minnesota, particularly in the vicinity of the national boundary line, from the mouth of Pigeon River to Basswood Lake; and (3) of sections of specimens illustrating the contact line between the Keweenaw series and the Eastern Sandstone of Keweenaw Point. The total number of thin sections added to our collections during the year has been 802, of which 292 were made at the Washington office and 510 at Madison. Of these, written descriptions have been prepared of 397; of which 56 are quartzites and sandstones, including quartzose conglomerates; 43 graywackes, graywacke slates, and graywacke conglomerates; 20 clay slates; 18 jaspery and cherty schists; 29 hornblende-schists; 32 chlorite-schists; 18 mica schists; 10 gneisses and granites; 6 felsitic porphyries; 162 greenstones, including diabases, diorites, etc.; and 3 crystalline limestones. In the course of the lithological work designed to aid in regional studies, several new points of general lithological interest have been met with, among which I may mention the discovery of a very interesting series of rocks, now mainly composed of quartz, which are manifestly but the products of alteration from once augitic rocks; and the discovery by Professor Van Hise of distinct secondary enlargements to the hornblende fragments which occur plentifully in the matrix of the great conglomerates of the Ogiskemanissi and Kekekabic Lakes. These enlargements are likely to prove of a great deal of interest and importance in connection with the origin of the crystalline schists. An account of these enlargements by Professor Van Hise will appear shortly in the American Journal of Science, the enlargements of quartz and feldspar fragments having already been described by us in some detail in Bulletin 8 of the Survey. Our lithological work has, of course, been very greatly curtailed by the loss of our material and grinding apparatus. Two investigations which we had in hand in particular we have had to set aside for the time. These are connected studies of Huronian basic eruptives and of Huronian jaspers and cherts.

Drafting.—The drafting work of the year has been mainly done by Mr. Merriam, although a little outside assistance has at times been required. Among the drawings of the year have been 37 figures and plates for publication in Bulletin No. 23 of the Survey, and three large-scale (two inches to the mile) working plats, two of Northeastern Minnesota, and one of the Penokee-Gogebic region of Wisconsin and Michigan. All of these drawings we have had to make at least twice on account of the loss of the first drafts.

Photography.—A large number of negatives representing occurrences in various portions of our field were taken during the summer and were developed and printed by Mr. Merriam after his return in the fall, but, as before stated, all were lost with the exception of a few prints.

Publications.—During the year there have been published as results of our work (1) a paper on the secondary enlargements in mineral fragments in certain rocks (Bulletin 8 of the Survey), by myself and Professor Van Hise; (2) a preliminary paper on the Archæan of the Northwest, published in the Fifth Annual Report; and (3) a paper on the divisibility of the Archæan in the Northwest, published in the American Journal of Science of March, 1885. In conjunction with Prof. T. C. Chamberlin, I have also prepared during the year an illustrated paper giving the results of our studies made together on the contact line between the Keweenaw series and the Eastern Sandstone on Keweenaw Point, which paper will appear as Bulletin 23 of the Survey. Professor Van Hise has also prepared a brief paper for publication in the American Journal of Science on secondary enlargements of hornblende fragments.

Besides the general supervision and management of the work, my own time in the office has been given chiefly to the preparation of publications as above named, and to the study and mapping of results. A good deal of time has also been given to the recovery of a portion of our collections from the ruins of the building in which they were stored. The numbers of these specimens having originally been painted on them were often sufficiently distinct for us to make them out with some little difficulty; and, although the specimens are all badly disfigured, we have still recovered perhaps a fifth of them in a condition sufficiently good to be of a great deal of assistance to us. In the latter part of November I visited Ann Arbor, Michigan, to confer with Dr. C. Rominger, the State geologist of Michigan, regarding certain questions which had arisen respecting a territory that had been examined by both of us. Dr. Rominger has aided me in every way in his power, and since our fire has presented us with a series of about five hundred specimens illustrating his reports on the Archæan regions of Northern Michigan and also with a copy of the manuscript of his still unpublished report on this region. I have also to acknowledge the receipt from Dr. A. R. C. Selwyn of a series of small specimens illustrative of the crystalline schists of East and West Canada. During the early part of April I visited Washington to confer with the Director of the Survey with regard to the future arrangement of my work.

Mr. Merriam is the only assistant on my division of the Survey who has been employed constantly throughout the year. The following have been employed on a *per diem* salary such times as their services were needed: Assistant Geologists C. R. Van Hise, C. W. Hall, W. W. Daniells, and W. M. Chauvenet; as office assistants, T. A. Polleys, N. M. Thygeson, J. Phillips, and J. R. Thompson; besides a number of woodsmen, canoemen, and packers.

All of which is respectfully submitted.

ROLAND D. IRVING,
Geologist.

Hon. J. W. POWELL,
Director United States Geological Survey, Washington, D. C.

REPORT OF DR. F. V. HAYDEN.

UNITED STATES GEOLOGICAL SURVEY,
MONTANA DIVISION,
Philadelphia, July 1, 1885.

SIR: I have the honor to submit herewith a summary of the operations under your direction in the Upper Missouri region for the year ending June 30, 1885.

During the preceding year the field work consisted of a general reconnaissance along the line of the Northern Pacific Railroad between Bismarck, Dakota, and Helena, Montana, which was preliminary to the more detailed work undertaken during the past season.

The broad area drained by the Missouri River and its branches on the eastern flanks of the Rocky Mountains is very largely a level prairie country, in which the strata are horizontal, or approximately so, for the most part. In this area the Cretaceous beds and the Laramie Group are the principal formations exposed. As we approach the main Rocky Mountains, the otherwise monotonous level becomes broken by a number of apparently distinct elevations, which form somewhat limited ranges, and afford excellent opportunities for the study of the geological structure of the country, as an extensive series of formations from the Archæan upward is usually exposed. Among these ranges in the area between the Yellowstone and Missouri Rivers are the Judith, Snowy, Little Snowy, Crazy, Highwood, Little Belt, Big Belt, and Bridger or East Gallatin Ranges. The latter lies on the east side of the Gallatin Valley, and in its present form is the eastern side of an anticlinal fold, from which the western half has been swept away by erosion. It rises conspicuously from the valley, having a trend at the south end almost north and south, gradually turning to the northwest as the range is followed to the northward.

The southern end presents a fine example of a complete overturn, in which the complete series of strata is tipped beyond the vertical.

The beautiful Gallatin Valley, stretching westward from the base of the range to the Three Forks of the Missouri, is determined by the former presence of a lake-basin, like many others in the Rocky Mountains, proof of the existence of which is seen in the remnants of deposits of fine sands and light-colored marl.

The region between the Bridger or East Gallatin Range and the Three Forks of the Missouri was selected for the initial work because it contains within its limits probably some of the best exposures of the rocks of the Northwest, representing the entire geologic scale extending from the presumably Archæan gneisses to the sands and loose superficial deposits of the Quaternary, thus affording one of the best opportunities for the study of the formations of the Upper Missouri region, and facilitating the making of the most complete section of the various beds.

Owing to the fact that it was only after the middle of July that the appropriations for work were available, it was the 1st of August before I was able to take the field at Bozeman, with Dr. Peale as my assistant.

Before the end of the first week in August the arrangements for field work were completed and we began work at the south end of the range. After some preliminary work along the western side of the range we proceeded to the junction of the East and West Gallatin Rivers, as this appeared to be the best locality to begin the study of the lower part of the geologic section.

As far back as 1860, Archæan, Silurian, and Carboniferous rocks were identified in the region adjacent to the Three Forks, and in 1872 considerable additional information was added to the data previously obtained.

The fossils collected then were mainly of Silurian age, and were discussed by Professor Meek. Still the stay in this region at that time was so short that the section could not be completed in detail. After obtaining data for this purpose during last season, we returned to the foot of the Bridger or East Gallatin Range about the 1st of September, with the intention of completing the study of the western side of the range. The weather, however, soon became so stormy that no work could be done, and snows coming on early, it was decided to postpone the field work to another season. Dr. Peale employed the remainder of the month of September in examining various spring localities in Montana, and came east early in October. A brief *résumé* of the formation examined during the season may be included here.

Like most of the mountain ranges in the Upper Missouri region, the Bridger or East Gallatin Range has a nucleus of Archæan rocks, not differing materially from those found in other portions of the extreme Northwest. They crop out beneath the sedimentary beds along the western side of the range for a distance of about 10 miles, occupying about a mile in width at the widest portion. The examination of the range not having been completed, it will suffice to say here that the rocks are mainly gray and red gneisses, which show distinct lines of stratification, and, although probably not conformable, dip in the same direction as the overlying sedimentaries, the lower beds of which are probably Silurian in age.

At the northern portion of the exposure the dip is normal, but as the south end of the range is approached the gneisses are overturned, together with the outlying sedimentaries.

The major portion of our time in the field was devoted to the study of the Cambrian rocks, which are well exposed near the mouth of the East Gallatin River.

A complete section was made here by Dr. Peale, and two lithologically well defined groups (separated by a quartzitic sandstone) were studied. To the lower one, which was carefully searched, without success, for organic remains, the name of East Gallatin Group has been provisionally applied. It is composed of a series of alternations of green and greenish-gray micaceous sandstones and clay slates (almost argillites), with thin bands of laminated limestones; 2,300 feet of these beds were sectionalized in detail without any traces of fossils being found.

The sandstones are in heavy beds and present a somber appearance, weathering on exposed surfaces to steel-gray and almost black colors and frequently breaking into cubical blocks. The slates are blue, yellowish-olive, green, and at some places red. In the limestone a concretionary structure is frequently noticed. For the upper group, lying above a well defined pink quartzitic sandstone, we have retained the name Potsdam. Green and dark purplish-red micaceous shales, mostly arenaceous, with occasional thin bands of limestone, make up this group, and many of the beds are highly fossiliferous. The collections have not been carefully studied yet, and we therefore simply refer to them in this general way at this time.

The central portion of the Bridger or Gallatin Range, from Reese Creek to the northern end, is composed almost entirely of the beds we have referred to the East Gallatin Group. The micaceous sandstones are somewhat more conglomeritic than are the same beds in the more western area, and are especially so at the south end near Reese Creek, where they often contain large angular masses of included gneisses, which upon a cursory examination do not appear different from the gneisses in the southern half of the range. At the latter place the East Gallatin Group is absent, as the Silurian (?) limestones apparently rest immediately upon the gneissic rocks.

The study of this portion of the range was abruptly terminated by the early appearance of the snows, and the problem at present remains unsolved.

The Silurian section, which is best exposed north of the East Gallatin, is perfectly conformable to the underlying beds. Its beds have not as yet been studied in the same detail as have the Cambrian. The total thickness as deduced from our investigations of last summer is probably about 800 feet. The beds consist of very hard blue laminated limestones at the base, passing up into gray, blue, and brownish limestones generally in the massive beds, with a few bands of the sandy shales. A part of the lower beds may be Potsdam.

The upper beds are more arenaceous, and have a persistent bed of gritty limestone or highly calcareous sandstone: it is sometimes difficult to say which it is. The lower beds are the only ones that up to the present time have yielded any organic remains, and they are highly fossiliferous.

One of the most important results of the summer's work was the identification of Devonian strata in the area north of the East Gallatin. The fossils collected were examined by Mr. C. D. Walcott, who identified twenty-three species. Of these he says: "Twelve are identical with the species occurring in the Upper Devonian of the Eureka district of Nevada; of the others, two are Upper Devonian species in New York State, and one, *Athyris hirsuta*, occurs at the base of the Carboniferous in the Eureka district. There is also a species of *Athyris* too imperfect for determination. The remaining forms are lamellibranchs belonging to five genera, and the species closely resemble those of the Lower Carboniferous of the Eureka district."

We supposed when these fossils were found that they were at the base of the Carboniferous. They occur in a series of argillaceous and calcareous shales, with thin bands of limestones and yellow sandy beds, with gray sandstones at the top. The lower shales are greenish and purplish in color. Below these are massive yellow and gray limestones that extend down to the black gritty beds which we have for the present assumed as the upper limit of the Silurian. In 1872 collections were made in this region (principally on the south side of the Gallatin Valley) which were examined by Prof. F. B. Meek. The fossils had considerable resemblance to Devonian forms, but he regarded the whole collection as belonging to the lower part of the Carboniferous, because no strictly Devonian types were contained among them. At the same time, however, he stated his belief that they were referable to a lower horizon than the Carboniferous collections brought in at the same time from adjacent portions of Montana.

In the light of the fossils collected last season, there can be but little doubt that the beds from which the specimens of 1872 were taken represent a portion of the Devonian; however, the determination of the fossils of last year's collection by Mr. Walcott enables us to make the first positive identification of the existence of Devonian strata in the Rocky Mountain region of Montana.

The work of next season will enable us to complete the section in detail. The limited time at our disposal having been devoted, as already indicated, to the lower portions of the section, we were not able to add much to our knowledge of the details of the Carboniferous, Jurassic, and Cretaceous formations. The Carboniferous consists mainly of heavy bedded blue-gray limestones, occupying a considerable area north of the East Gallatin, and forming, in great part, the summit of the Bridger or East Gallatin range. At the upper part is a heavy bed of quartzite, above which arenaceous limestones occur, carrying Jurassic fossils, among which *Rhynchonella myrina*, *Belemnites densus*, *Ostrea strigilecula*, and *Camptonectes bellistriatus* were most abundant.

This group is coextensive with the Carboniferous, not only at the locality just described, but in the Bridger or East Gallatin range. In the latter place the lithological characters appear to be different, but our data are not yet quite sufficient to determine the reasons for the changed conditions.

The upper portion of the Jurassic grades into sandstones, upon which rests a quartzite which we recognize as the Dakota Sandstone.

Above this is a series of shales and sandstones, with some beds of limestone, which we refer to the Cretaceous without as yet attempting to make out the various subdivisions, for the fossils have not been found to warrant it. A few have been found in some of the upper beds which present the facies of the Fort Pierre group, but still the beds are somewhat different from those usually so referred and some of the fossils appear to be new.

Above these beds lies the "Coal group" (so named in 1872), which stretches from the east side of the Bridger or East Gallatin range to the Crazy Mountains. A small basin of these beds also lies north of the East Gallatin, and from the latter a few fossils, possibly of Laramie age, were obtained in the coal beds outcropping here. Southeast of Bozeman, near Bozeman Pass, the same coal beds are quite extensively mined. The exact determination of the age of this group is one of the problems still to be determined. The proximity of the deposits to what was once a shore line has caused not only a thickening of the sediments, but a great change in their quality and composition.

In nearly all the valleys of the Upper Missouri region we find a greater or less development of lake deposits in basins which range in size from a few acres to many square miles. They are usually found along the courses of the rivers. The Gallatin Valley is one of these basins, and the lake which once covered it extended from the flank of the Bridger or East Gallatin range and the hills southeast of Bozeman westward and northward, taking in the main portion of the area drained by the Three Forks and closing up in the cañon just below the junction of the Gallatin, Madison, and Jefferson Rivers.

The deposits now remaining are but small remnants of the original mass. When the cañon of the Missouri was worn through, the lake was drained, and during this process and subsequently several hundred feet of light-colored marls and sands were carried down the Missouri River. Traces of these beds are now found in the valleys of the three rivers, which for twenty or thirty miles above their mouths are not very widely separated.

The space at command here will permit only a brief reference to their occurrence on the east side of the Gallatin Valley. They are best exposed just east of Bozeman, where they consist mainly of fine-grained sandstones, with occasional conglomeritic beds, the entire thickness reaching from 600 to 800 feet.

On Dry Creek, 15 miles farther north, the lower beds are coarser and rest on white limestones, which are conformable and dip slightly toward the south. In most places the beds are nearly horizontal, but inclined enough to show that, although they were laid down since the great outlines of the mountains had reached nearly their present condition, still there has evidently been some movement since their deposition. Whether the beds are of Miocene or of Pliocene age cannot be positively stated, as there is no proof at present as to either view. They have generally been referred to the Pliocene, and as there is not at present any evidence to the contrary, we will so consider them. As to the Quaternary, our studies up to the present add but little to our knowledge. It is doubtful if there is any proof of a general or traveled drift in the Gallatin Valley. On some of the highest hills made up of the Pliocene beds, coarse, angular, and smooth water worn pebbles occur, many of them igneous rocks similar to those found in place in the mountains some distance to the southward. The drift in the more open and level portions of the valley is probably all local in its origin, being derived from the Gallatin Mountains bordering the southern part or edge of the valley. As we recede from them this drift becomes finer. Along the streams the alluvial deposits are prominent and give to the valley some of its best farming lands. Towards the north these alluvial areas are largely increased in size.

This brief *résumé* will be sufficient to indicate in a general way the character of the rocks in the region selected for our initial work, and in which we hope to complete a detailed section during next season. It is doubtful whether any other area in the Upper Missouri region presents better facilities for this purpose.

Our office work during the winter has consisted mainly of the study and revision of the notes of the summer's work. In addition to this, Dr. Peale has prepared a statistical paper on the mineral waters of the United States, which will appear in the forthcoming report on the Mineral Resources of the United States.

Progress has also been made on the bibliography of mineral waters.

Mr. L. Withers, who was detailed early in the winter to assist Dr. Peale, has rendered efficient service.

Very respectfully, your obedient servant,

F. V. HAYDEN,
Geologist.

Hon. J. W. POWELL,
Director United States Geological Survey, Washington, D. C.

PEPORT OF MR. ARNOLD HAGUE.

UNITED STATES GEOLOGICAL SURVEY,
YELLOWSTONE PARK DIVISION,
Mammoth Hot Springs, Wyoming, July 1, 1885.

SIR: I have the honor to submit herewith the following report of operations conducted under my charge during the year ending June 30, 1885.

Field work in the division of the Yellowstone National Park has been confined to the Park and the country immediately adjoining its borders.

On June 20, 1884, Mr. C. D. Davis reported to me, in New York, and, after a few days occupied in making the necessary preliminary preparation, proceeded to Bozeman, Montana, to thoroughly equip a camp for the season's work. Under your instructions I left New York for the Park, reaching Mammoth Hot Springs July 23, where I met Mr. Davis, who had already established camp awaiting my arrival.

At the Mammoth Hot Springs I remained several days, planning field work and arranging for a vigorous and energetic examination of the country, with the intention of keeping in the field one and frequently two and three side parties away from the main camp. The organization of the party was an efficient one for the work and consisted of the following assistants: In geology, Mr. Joseph P. Iddings, Mr. W. H. Weed, and Mr. George M. Wright; in chemistry, Dr. F. A. Gooch; in physics, Dr. W. H. Hallock; and Mr. C. D. Davis, special disbursing agent and general manager of the camp. Mr. W. E. Sanders, of Helena, Montana, a student from the School of Mines of Columbia College, served as a volunteer assistant during his summer vacation.

The first main camp after leaving the Springs was established on Indian Creek, a branch of the Gardiner River, from which place I made a general reconnaissance of the Gallatin Range. This range lies in the northwest corner of the Park, and is of special interest, as it constitutes a well defined western rim of the plateau country and is the only range of sedimentary rocks rising above the great volcanic flows which nearly everywhere cover the Park.

Geological interest in the range centers in the remarkable intrusions of igneous rocks found penetrating the whole series of sedimentary beds from the Silurian to the Colorado Cretaceous. Indeed, they form such large masses as to be but little inferior to the Paleozoic and Mesozoic strata. The study of these intrusive and interbedded crystalline rocks in connection with the neighboring massive flow will be of great scientific interest, and some important results may be looked for from a thorough examination of the material collected.

Erosion has played an active part in bringing about the present physical features of the range and the whole mountain region has been greatly modified by ice action. The glacial phenomena are worthy of special study.

I was desirous of examining the mountains for any indications of mineral deposits that might occur there, in order that, if the boundaries of the Park were to be defined anew by law of Congress, the propriety of still including the range within the reservation might be fully understood. Nothing in this preliminary survey led me to believe that there existed any good and sufficient reason for throwing the Gallatin Range open to settlement. On the contrary, its great beauty and its numerous haunts of large game convinced me of the desirability of retaining the country within the national reservation.

From the Gallatin Range I moved southward, remaining some days at the Norris Geyser Basin, and thence to the Lower Geyser Basin, where I made a permanent camp. From here the main party moved to the outlet of Yellowstone Lake, while a detachment established a camp in the Upper Geyser Basin. The party at the Geyser Basin consisted of Dr. Hallock, Dr. Gooch, and Mr. Weed, their special duties being a continuation of the studies of the previous summer upon the geysers and hot springs of that famous locality. Leaving most of the party at the lake, I started on August 30 to make a reconnaissance survey of the area of country lying between the present southern boundary of the Park and the forty-fourth parallel of latitude, a belt of country about eight miles in width.

The special object of this trip was to examine the country with reference to the advisability of extending the area of the national reservation to the line mentioned. This involved questions as to the geological character of the region, the probability of its ever becoming a mining country, the value of its timber and the necessity of its preservation, and also whether there was any land that would ultimately be needed for the purpose of settlement. My main route of travel followed the continental divide lying between the Yellowstone and Lewis Lakes, thence down Snake River to Jackson's Lake, situated just south of the proposed boundary. From here I desired to move eastward over the mountainous country lying between Jackson's Lake and the waters of the Upper Yellowstone, recrossing the Great Divide through Two Ocean Pass, made famous by the traditions of the earlier mountaineers and trappers. It has only been visited by a few adventurous travelers, and will probably long remain buried among the more inaccessible recesses of the Rocky Mountains. General Raynolds makes mention of it in his report of the explorations of the Yellowstone in 1868, his interest in is being aroused by his guide, the famous Jim Bridger. He failed, however, to penetrate the country. Both Captain Jones and Dr. Hayden passed through it on their way south from the Yellowstone Lake, but they both kept to the mountains and crossed Twogotee Pass to the headwaters of Wind River. I was unable to learn of any one who had corssed directly from Snake River to the Yellowstone, and the few prospectors and trappers met in the neighborhood generally spoke of the country as a rough and unknown region, barely possible to travel.

I determined, however, to follow up Pacific Creek and take as direct a course as possible to its sources in the meadows described by Dr. Hayden. From the information I had gathered and the erroneous character of the maps I was prepared for a difficult bit of travel. I found, to my surprise, with the exception of one or two miles of rough country, that the stream could be followed without any serious hindrance to its source in the broad meadows, high up in the mountains. From this same meadow a small stream, known as Atlantic Creek, flows eastward, and empties its waters into the Upper Yellowstone.

Unfortunately we were caught on the summit in a severe snow-storm, although early in the month of September. Snow to the depth of 15 inches covered the ground. This not only caused a delay, but prevented us from determining accurately the conditions governing the supply and discharge of the waters. It is probable that the divide between Atlantic and Pacific Creeks is but a few inches in height. The conditions observed here are not unlike those seen in many places on flat, plateau-like country, the difference being that here they are on a grander scale and more than usually striking and impressive. The place is one of great beauty. If the Park limits should be extended to the Forty-fourth parallel, Two Ocean Pass will be within the reservation.

Owing to the heavy snowfall in the mountains, the delays caused by the storm, and the consequent running short of provisions, I deemed it prudent not to cross the Sierra Shoshone Range, but to join the main party at the north end of the lake. With this intention I followed down the Upper Yellowstone, skirted the east shore of the lake, and forded the river five or six miles below its outlet. I reached camp September 14.

A few days later the party stationed in the Upper Geyser Basin, having completed the work for the season, returned to the main camp. On September 19 the camp broke up at the lake, the main party returning to the Mammoth Hot Springs by slow marches. With a small party I recrossed the Yellowstone River, in order to explore the little visited country lying between the Grand Cañon and Amethyst Mountain. It is a rough country, for the most part heavily timbered, and remarkable for its many areas of both active and extinct thermal springs. They proved to be of great interest, but not so impressive as those in the more frequented portion of the Park. Late in September the two parties came together at the Mammoth Hot Springs. On October 2, I started for New York, with Dr. Gooch and Dr. Hallock, leaving the rest of the force in the field with instructions to remain till about the middle of the month unless forced to leave off work by the inclemency of the weather. Daily snow storms, however, compelled them to abandon the field, and they left the Park on October 9, reaching Livingston by the train on the branch road from Cinnabar. Mr. Davis immediately returned to Bozeman to store the camp property and to close up all business for the season.

The field season in the Yellowstone Park, although limited to about eleven weeks, was in nearly every respect successful. Special attention was given to the volcanic rocks of the plateau and those encircling the Geyser Basin and Yellowstone Lake. The relations of the glassy varieties of the acidic rocks, which form such characteristic masses in the Park, to the more crystalline products have been carefully worked up.

Dr. F. A. Gooch rendered most efficient aid in his special department by his untiring energy and the suggestiveness of his inquiries. His attention was confined almost exclusively to chemical questions connected with the thermal waters of the geyser basins and Mammoth Hot Springs. A large number of samples of waters were collected from the most characteristic geysers and springs. Many of these geyser waters from the different basins were carefully evaporated in a copper still on the ground, and the concentrated material was shipped to the chemical laboratory in Washington for complete analysis with the intention of testing the waters for the rarer alkalies and heavy metals. I desire to determine, if possible, whether any difference, however slight, exists in the waters from the Upper Geyser Basin, Lower Geyser Basin, and the Norris Basin. While I do not look for any characteristic difference, the result of the analyses will throw much light upon the questions connected with the source of the thermal waters. Much attention was given to the examination and relations of the great variety of secondary products derived from the action of these waters upon the surrounding rocks. Large collections of material were made for study and analysis in the laboratory. The phenomena connected with the thermal activity in the Park will for many years present problems of interest to geologists and chemists.

Dr. Hallock continued his investigations of the previous year upon the physics of geyser action. His determinations of the temperatures in the geyser vents and deep seated reservoirs by thermo-electric methods were successful and the results when published will prove of great interest. While in general his observations confirm the Bunsen theory of geysers, a study of the varied phenomena exhibited in the Park has made it possible to add much that is new to our knowledge of their mode of action.

No marked changes were noted during the year in any of the hot-spring areas of the Park, although variations of temperature and in some cases the dying out of small springs were observed. In the latter case the waters frequently found other vents in the immediate neighborhood. The most notable changes have occurred at the Mammoth Hot Springs. Springs that were known to have been active from 1871 to 1883 have become extinct during the past year. After a careful survey of the whole field I fail to discover any diminution, on the whole, in the activity of the springs or in the discharge of hot waters.

It may be well to make special mention here of the Broad Creek area of hot springs. The locality is one which has been little visited and is most difficult to find. The springs are situated in a trough-like expansion of the ravine of the main stream and that of a small tributary branch. Decomposition has thoroughly altered the rhyolite of the ridges into a soft earthy material of brilliant shades of red, yellow, and white, only surpassed by the Grand Cañon. Active sulphur vents cover the slopes of the hills over several acres of ground. The most noticeable spring I named "The Whistler," from the loud noise caused by a powerful steam jet issuing from an orifice 1½ inches in diameter and flaring above into a funnel-shaped opening.

The vent is on the right bank of the stream and about 10 feet above the water. A column of steam 90 feet in height is forced upward with a shrill powerful whistle On the opposite side of the stream there is an active boiling pool of clear water 10 by 12 feet in diameter. Although not seen in action, all the evidence indicates that it is the basin of an active geyser.

In regard to the definite boundaries of the Park, upon which final action must soon be taken by Congress, I have no further suggestions to add to those already expressed in my former reports. A more accurate knowledge of the country confirms me in my previous judgment as to the proper limitations of the national reservation. These suggestions were embodied in Senator Vest's bill providing for the regulation and improvement of the Yellowstone National Park, which, however, failed to become a law during the last session of Congress. Numerous letters and conversations with people interested in the Park, advocating either a reduction of the present area or a still further enlargement than that contemplated in the bill, make it clear to me that the interests of the Park are best subserved by adopting the boundaries proposed in the recent bill before Congress. In my opinion the boundaries of the Park should be defined practically as follows:

The northern boundary, starting at the one hundred and eleventh meridian, should coincide with the forty-fifth parallel of latitude to the intersection of the meridian 109° 30′, thence due south along said meridian to the forty-fourth parallel, thence due west along said parallel to its point of intersection with the meridian 111°, thence due north along said meridian to the place of beginning.

Upon the arrival of my assistants in New York, preparations were immediately begun to pack the large collections accumulated in the rooms occupied by the Geological Survey in the American Museum of Natural History. Among others, this included the collections of the "Geological Exploration of the Fortieth Parallel," which have recently been placed in the National Museum at Washington.

The office having been removed to Washington, the early part of the winter was occupied in arranging anew the collections forwarded from New York, after which work was begun on the notes and materials of the previous season.

In connection with other work Mr. Iddings has made a careful microscopic examination of the obsidians and volcanic glasses which form such enormous masses in the Park and which bear directly upon many of the geological problems of the region. His work, however, is a special study upon spherulitic structure and the mode of occurrence of the so-called "lithophysæ," so characteristic of the acidic glasses of obsidian cliffs.

In February I submitted for your approval for publication a paper by Mr. Joseph P. Iddings and myself entitled "On the development of crystallization in the igneous rocks of Washoe, Nevada, with notes on the geology of the district" which forms Bulletin No. 17. It presents the results of a searching investigation upon a large amount of material from Mount Davidson and the Sutro Tunnel, showing the gradual transition from the glassy to the granitic structure. The facts brought out appear to me to warrant the assertion that difference in structure in igneous rocks of the same chemical composition is mainly the result of consolidation under varying degrees of heat and pressure. In other words, the degree of crystallization is an expression of the rate of cooling and is independent of geological age.

Very respectfully, your obedient servant,

ARNOLD HAGUE,
Geologist in Charge.

Hon. J. W. POWELL,
Director United States Geological Survey, Washington, D. C.

REPORT OF CAPT. C. E. DUTTON.

UNITED STATES GEOLOGICAL SURVEY,
VOLCANIC DIVISION,
Berryvale, near Mount Shasta, Cal., June 30, 1885.

SIR: I have the honor to submit the following brief report of the work performed by me and under my supervision during the fiscal year ending this day.

It has been in contemplation for the last two years that I should undertake the study of the Cascade Range. Preliminary thereto it was necessary that a certain amount of progress should be made in the preparation of suitable maps of the region in question, and these were begun by the topographic force, under the charge of Mr. Gilbert Thompson, in the year 1882. Some fragmentary material suitable to the purpose had been obtained by the survey under Lieut. G. M. Wheeler, United States Engineers, and proved to be of great service. It covered, however, only a small part of the area under consideration, and a more extended and complete survey was planned and begun under Mr. Gilbert Thompson and carried forward by Mr. M. B. Kerr during the years 1882-'83-'84.

Meantime it was thought desirable to obtain some preliminary view of the most conspicuous and easily recognizable geological features in advance of the completion of any part of the map. Accordingly, with your approval, I instructed Mr. J. S. Diller, in 1883, to organize a small party at Mount Shasta, and to proceed thence up the eastern side of the Cascade Range, along the border of the Klamath Lakes and the valley of the Des Chutes River as far as the Dalles of the Columbia, and to cross near Mount Hood into the valley of the Willamette and return southward up that valley to his starting point. This journey Mr. Diller accomplished under great difficulties and with much credit to himself. Unfortunately the rainy season overtook him before the journey was completed and interfered much with his work. But he brought back with him information of great service in planning subsequent and more systematic work.

In 1884 Mr. Diller began a detailed study of Mount Shasta and the country immediately adjoining it. In the course of the season he succeeded in discriminating the various masses of which it is composed so far as now disclosed to view and in determining their lithologic characters. He also ascertained the characters and relations of the lavas emanating from the parasitic cones and from the vents which are scattered thickly around its base and flanks. The physical features of the mountain, its structure, its glaciers, and its fragmental ejecta were also studied with great care, and all these results have been delineated by him upon a provisional map. The map represents an area of 400 square miles where the difference of elevation is 11,000 feet. An examination of the country on all sides of Mount Shasta, but especially in the Shasta Valley and Pitt River region, resulted in the discovery of coal in the Chico group of the Cretaceous formation. On Mr. Diller's return to Washington a petrographic laboratory was fitted up under his direction and supplied with the apparatus necessary for the investigation of rocks according to the most approved methods. In one room mineral analyses of rocks are made by means of heavy solutions, an electro-magnet, etc., and chemical reagents. Another room is set apart for the investigation of the crystallographic and optical properties of minerals and the determination of rocks by microscopical researches. During the year numerous rocks were identified and described for various geologists of the Survey. The eruptive rocks found in Kentucky proved to be peridotites of considerable importance, and will be fully described in a bulletin.

In consequence of much interesting information brought back by the topographic parties that had been engaged in making the map of the portion of New Mexico which embraces Mount Taylor, it was deemed advisable that I should visit that locality for the purpose of studying the remarkable features there presented. I left Washington July 1, 1884, for Fort Wingate, and organized a small party, with which I proceeded to Mount Taylor and spent five or six weeks in its vicinity. The remainder of the season was devoted to the study of the Zuñi Mountains, which are hard by Mount Taylor. The results obtained by the season's work have already been put into the form of a memoir, which has been transmitted to you for publication as a paper connected with this report. The preparation of this memoir occupied the entire winter and spring.

The occurrence of several notable earthquake tremors in the Atlantic States last summer and autumn, and the fact that they are much more numerous than is generally supposed, led to some preliminary measures looking to the establishment of systematic observations of such phenomena. A consultation was held with Prof. C. G. Rockwood, of Princeton, Mr. W. M. Davis, of Harvard, Prof. Cleveland Abbe, of the Signal Service, and Mr. H. M. Paul, of the Naval Observatory. It was the opinion of all who took part in the conference that the only practicable scheme was to rely upon the voluntary and unpaid co-operation of individual observers who might be induced to devote the necessary time and attention to it; also, upon the assistance of such astronomical observatories as might be disposed to watch and read the instruments and their records, and upon the assistance of the Signal Service and other Government bureaus which have permanent stations scattered throughout the country. It was thought that the Geological Survey might furnish the observers with instruments and receive the reports. As the observations would require to be very numerous and well scattered in order to be of value, some suitable instrument was needed which should be inexpensive and simple and require the minimum of care and attention. As none such was known, Mr. Marvine, of the Signal Service, kindly offered to attempt to devise one. The task was a difficult one, but he at length produced a design which seemed so well adapted to the case that a model was ordered and was nearly completed at the time of my departure from Washington. Mr. W. M. Davis also began a bibliography of earthquakes, which was much needed in this connection; and for this undertaking grateful acknowledgment is due to General Hazen, the Chief Signal Officer, for his courtesy in furnishing a large number of titles.

I have to regret that the unusually severe pressure of geological office work did not permit me to devote as much time to the organization of these observations as I could have wished, but in the absence of suitable instruments very little could be accomplished in this direction. It is my hope to be able to take it up with energy after my return from the field next autumn.

On the 18th of May I left Washington for northern California to enter upon the study of the Cascade Range, and I am at present engaged upon it. The very brief time thus far spent only enables me to report that I have made a very interesting visit to Lassen's Peak, and found many instructive themes of study. These will be duly reported upon in the future.

Very respectfully, sir, your obedient servant,

C. E. DUTTON,
Captain of Ordnance.

Hon. J. W. POWELL,
Director United States Geological Survey, Washington, D. C.

REPORT OF MR. S. F. EMMONS.

UNITED STATES GEOLOGICAL SURVEY,
ROCKY MOUNTAIN DIVISION,
Washington, D. C., June 30, 1885.

SIR: I have the honor to submit the following report of operations in the division of the Rocky Mountains mining geology, under my charge, for the fiscal year just completed.

The scientific corps of the division was strengthened at the commencement of the year by the addition to its number of Mr. George H. Eldridge, formerly geologist of the Northern Transcontinental Survey, who fills the vacancy caused by the resignation of Mr. Ernest Jacob in the previous year. With this exception the working force remains the same that it was at the date of my last annual report.

FIELD WORK.

The geological investigations in this division for which the field work was as yet uncompleted at the commencement of the year were those of the Denver Basin and of the Gunnison or Crested Butte region.

The geological examination of the former region had already been carried as far as it could be done to advantage without a detailed map. The field work for this map was nearly completed at the end of the last fiscal year, when Mr. Karl was summoned to Washington, to be assigned to topographical duties in Massachusetts. It is now expected that these topographical data will have been plotted, so that the map can be used in the field during the coming autumn, after the close of the season for work in the mountainous region around Crested Butte, and that the geological report on the region can then be rapidly prepared for the press.

In obedience to your instructions, I took the field in the Gunnison or Crested Butte region about the 1st of August, with a mixed party of geologists and topographers. The former consisted of Messrs. Cross, Eldridge, Eakins, and Smith; the latter of Mr. W. H. Leffingwell, to whom had been assigned the duty of completing the work left unfinished by Mr. Karl the previous season, and the party left by the latter, consisting of Messrs. Dür, Thompson, Van Diest, and Waters, with Naval Ensign Wilkinson. The topographical work was finished, and that portion of the party broken up early in September, the geologists continuing in the field until driven away by snow early in October. After this time Mr. Eldridge made some sections of the Paleozoic formations in the Arkansas Valley, in order to establish a geological connection between the deposits of the eastern and western slopes of the Rocky Mountains, while Messrs. Cross and Smith went to the Leucite Hills of Wyoming to obtain a series of educational specimens from that locality, and study more carefully than had hitherto been done the geological relations of those singular rocks.

The geological work in the Gunnison region was necessarily not final, as the topographical basis upon which field observations could be actually plotted was not yet completed. The admirable reconnaissance observations of Mr. W. H. Holmes, made under the auspices of the Hayden survey in 1874, and his graphic illustrations of the great fault-fold of the Elk Mountains, are already familiar to geologists, and are in themselves sufficient to show the necessity of a carefully detailed study of this region from a purely structural point of view. The immense development of intrusive masses of igneous rocks of earlier age than the Tertiary volcanics, and their relation to the formation of ore deposits, which have been suggested by my investigations in the Leadville region—points which, owing to the limited development of microscopic petrography at the time of his investigations, necessarily secured but little attention—have a great importance from a purely scientific as well as from an economic point of view. Further than this, the large development of ore deposits and of valuable beds of anthracite and good bituminous coking coals in the region render its accurate examination of the greatest economic importance to the whole Rocky Mountain region.

In carrying out this work, which, from the great complexity of the geological problem, and the natural obstacles in the way of extremely high and precipitous mountains and short season in which field work is possible, will necessarily occupy a long time, my plan has been to assign to Mr. Eldridge the study of the stratified and to Mr. Cross that of the eruptive rocks, reserving to myself the duty of correlating and generally verifying the work of each. In the short field season of the past year our combined energies were devoted primarily to determining accurately from paleontological and stratigraphical evidence the different geological formations exposed in the region, which necessarily involves a preliminary determination of the structural relations; and, secondarily, to the determination of the age and relations of the different bodies of eruptive rocks, and to the collecting of sufficient specimens for microscopical study.

Such determinations must of necessity be only provisory, in some cases consisting only in the establishment of two alternative solutions of a given problem, of which the true one must be sought by further investigation, map in hand. In the course of last summer's work, however, I observed two facts, hitherto unremarked by geologists who have visited the region, which have so important a bearing upon the history of the Rocky Mountain system as a whole that, although some further observations are still needed to render them complete, I think it is best to present them here in their incompleteness, since the suggestions they offer may be of use to other geologists. These facts are, first, the existence of a nonconformity at or near the commencement of the Jura, and, second, the existence of land area subject to erosion, and a consequent nonconformity, near or before the middle of the Carboniferous period. In other words, there have been two dynamic movements in this region earlier than the close of the Cretaceous, whose influence, moreover, was not of an exclusively local nature, but probably widespread throughout the Rocky Mountain region, though not often producing a sufficient discordance of angle to be very prominent.

Jurassic nonconformity.—The facts which prove the first nonconformity are briefly these: The western two-thirds of the area covered by our map is occupied by Cretaceous beds; the eastern third, which is in the axis of the Elk Mountain uplift, consists of Paleozoic beds, with a very large development of igneous rocks throughout the whole area. The Dakota, or lower member of the Cretaceous, consists of a series of sandstones, often quartzitic and frequently of buff color, including the characteristic Dakota conglomerate, below which are a series of variegated shales, with local development of limestone, succeeded by a second heavy sandstone, often quartzitic in texture, the whole having a thickness of 500 to 800 feet. There can be no doubt, from its position below the black shales of the Colorado Cretaceous and from its lithological character, that the upper part of the series represents the Dakota Cretaceous. The lower part corresponds very closely in lithological characteristics with the Jurassic formation as developed at the east base of the Rocky Mountains; it has, moreover, been considered Jurassic by the geologists of the Hayden Survey; but as yet no paleontological evidence has been obtained to prove this beyond all possibility of a doubt. This series of beds is extremely easy to trace by the strong contrasts of the hard white quartzitic sandstones with overlying soft blue-black shales of the Colorado Cretaceous, and almost equally as well defined in regard to the beds which succeed them on the east or below in geological horizon. At the northern edge of our map, along Copper Creek, at the north base of White Rock Mountain, these beds are succeeded below, in apparent conformity of angle, by the Red Beds and the conglomerates and limestones of the Carboniferous. As one follows the strike of the beds southward, along the west flank of the Elk Mountains, this series of white quartzitic sandstones is found to come in contact with successively lower beds — first with the Carboniferous conglomerates and limestones; next with the siliceous beds, presumably Cambrian, beneath these; and finally in the southern portion of the map they rest directly on the Archæan. Moreover, in some places, notably along the north wall of Cement Creek, they are seen to rest unconformably on the basset edges of the lower limestones. Whether the Red Beds represented here are Triassic or simply the upper part of the Carboniferous it is as yet impossible to determine. However that may be, it is evident from the above facts that somewhere between the close of the Carboniferous and that of the Jurassic period (probably near the commencement of the latter) there was a dynamic movement here, by which land areas were formed and subjected to considerable erosion before the deposition of the Jura-Cretaceous beds.

The fact that on the Hayden Atlas of Colorado, Cretaceous or Jurassic beds are often colored as resting directly on the Archæan shows that this movement was probably widespread. I myself have observed quartzitic sandstones colored in the atlas as Dakota, and which are undoubtedly later than Trias, resting directly on the Archæan in the valley of the Blue River in Middle Park. Already in the time of the survey of the fortieth parallel we thought we had found evidence of a Jurassic nonconformity in the Wasatch Mountains, but it was so uncertain in character that it was not insisted on.

Carboniferous nonconformity.—The Paleozoic formations in the Elk Mountain region have a generic resemblance to those already studied in the Mosquito Range; that is, they consist of a series of red sandstones with some limestones at the top, a heavy belt of conglomerates, showing evidence of formation in shallow waters and on the borders of a land area, in the middle and at the base a series of evenly bedded limestones and quartzites of inferior thickness, resting directly on the Archæan. The most striking feature in regard to the heavy belt of conglomerates is the fact that their pebbles consist largely of limestone, a blue-gray or drab rock like the ordinary Carboniferous or Silurian limestones of the Rocky Mountains. This proves that at the time of their formation a land area existed composed in part at least of limestone beds, from whose abrasion the material for their conglomerates was derived. As no limestones are found in the Archæan formation of the Rocky Mountains, it follows that these limestones must be of later age, and therefore that there must have been a movement since the close of the Archæan. It was at first thought that this movement was probably before the Carboniferous epoch and the pebbles of Silurian formation, which would account for the apparent absence of the Devonian formation in the Rocky Mountains, an absence the more singular since its beds are so fully developed in Nevada and have been observed in the Wasatch Mountains. The exact stratigraphical location of the nonconformity could not be determined, because thus far the spaces between the conglomerate beds and the lower limestones and quartzites, resting directly on the Archæan, have been found entirely covered, and the apparent discrepancy of angle between the two series cannot be affirmed to be definitively proved. In the lower series, however, no limestone pebbles are found in the conglomerate beds. The fossils obtained, which have been examined by Mr. Walcott, show that a portion of this lower series is of Carboniferous age; therefore the dynamic movement occurred during the Carboniferous period. This is further evidenced by a few somewhat indistinct fossils obtained from the limestone pebbles themselves, which have a distinctly Carboniferous facies. Silurian and Cambrian fossils have not yet been found in the region, but it is possible that further search may disclose them in the lower beds; these horizons must, in any event, be extremely thin.

Hitherto there has been supposed to be but one great nonconformity in the Rocky Mountain region, viz, between the Cretaceous and Tertiary periods. Those above noted were evidently less important than the great movement which marks the age of the present uplift of these mountains, and possibly of very much more limited extent, since they have not hitherto been noted by geologists. A slight discrepancy of angle or the absence of part of a formation might readily escape notice in the general examination that has hitherto been made of this region, unless attention were specially called to a particular horizon by the knowledge that such a nonconformity exists in some locality, and for that reason I am led to believe that when the above facts are generally known, similar evidence will be found in many other localities.

As will be shown in my forthcoming report on the Silver Cliff region, I have evidence that the Wet Mountain Valley was a land area in Carboniferous time, which must have presented a precipitous escarpment to the west, from which huge masses of Archæan rocks fell into the sea and formed a peculiar conglomerate of immense subangular fragments, apparently corresponding in age to the Weber grits of the Mosquito region and to these limestone conglomerates of the Elk Mountain region. During the field work of the coming season I trust that additional data will be obtained which will enable us to determine more accurately the period of these two nonconformities.

After the close of the season in the Gunnison region it is hoped there will be sufficient time and funds available to complete the field work on the Denver Basin before winter sets in.

OFFICE WORK.

In spite of short field seasons, it is generally found that the material gathered during the summer months is sufficient to furnish employment during the rest of the year in its microscopical and chemical investigations. The preparation of manuscripts for the press has not progressed, from various causes, as rapidly as had been anticipated. The census volume on "Statistics and Technology of the Precious Metals," of which the manuscript was submitted two years ago last February, is at length printed, and no more time will be required by that. During the spring Bulletin No. 20 was sent in to the printer containing "Contributions to the Mineralogy of the Rocky Mountains," by Messrs. Cross and Hillebrand. The manuscript for the Leadville report is now ready for the printer, with the exception of rearranging certain tables. The maps for the Ten-Mile and Silver Cliff reports, respectively, have been sent to the Public Printer to be engraved, and the manuscript of each is partially completed. These will be followed in order of publication by the report on the Denver Basin, including a report on the Golden Mesas, which was completed some time since, but which awaits the determination of certain stratigraphical questions for which the finished map is necessary. These will be followed later on by the report on the Gunnison or Crested Butte region.

Very respectfully, your obedient servant,

S. F. EMMONS,
Geologist in Charge.

Hon. J. W. POWELL,
Director United States Geological Survey, Washington, D. C.

REPORT OF MR. GEO. F. BECKER.

UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF THE PACIFIC,
Steamboat Springs, Cal., June 30, 1885.

SIR: At the beginning of the present fiscal year I had reached a point in the investigation of the quicksilver deposits of California at which it became absolutely necessary to acquire more definite information as to the age of the metamorphic rocks of the Coast Ranges and as to the tim- relations of the epoch of metamorphism. From a study of the structe ure, combined to a certain extent with paleontological reasoning, I had indeed reached certain conclusions, but the co-operation of a paleontological specialist was essential to a satisfactory elucidation of the subject. At my request and with your approval Dr. C. A. White consented to examine the Mesozoic and Cenozoic faunas with me, so far as the questions which had arisen in my work made it necessary, and for this purpose he joined me late in June, 1884, at San Francisco. Besides examining my collections of fossils Dr. White visited New Idria and its neighborhood with Mr. H. W. Turner, my assistant, after which we visited a considerable number of points together, including Martinez, Monte Diablo, Pence's Ranch, Horsetown, Bass's, the McCloud River, the Mariposa estate, California; Roseburg, Oregon, and others. In pursuance of the same work I later revisited Knoxville and made a trip along the coast from the Russian River to beyond the mouth of the Wallala River.

I had the great satisfaction of finding that Dr. White was led to the same conclusions on purely paleontological grounds which I had reached mainly from structural considerations, and further, that as a general geologist of long experience, he fully agreed with me as to the indications of the structure. We have given the main results of the joint investigation in Bulletins 15 and 19, but a brief statement of the principal conclusions reached will not be out of place here.

The labors of the State Geological Survey, under Professor Whitney, showed that some of the metamorphic rocks of the Coast Ranges belong to the so-called Shasta Group, which, according to Mr. Gabb, included both the Neocomian and the Gault. Above the Shasta Group come the Chico beds, corresponding, in Gabb's opinion, to the upper or lower Chalk of Europe. Above the Chico, and conformable with it, occur the Téjon strata, referred by Conrad, who first described their fauna, to the Eocene, but by Gabb to the Cretaceous. Upon the Téjon lies the unquestionable Miocene. In several places Professor Whitney found the Miocene resting unconformably upon the metamorphic rocks, and considered it probable that in one locality, at all events, the most-extensive disturbances of the Cretaceous, as well as the greater part of the metamorphic action upon it, had taken place before the deposition of the Tertiary. He records no other nonconformity among the series mentioned above. The main uplift of the Coast Ranges Professor Whitney refers to a post-Miocene disturbance. The gold belt was considered as pre-Cretaceous, Meek having determined some fossils from the Mariposa estate as Jurassic mainly on the ground that Ancella is a Jurassic genus.

Freely employing the excellent geological observations recorded in the first geological report of the State survey, Dr. White and I have pushed our conclusions further. There is, with one exception, no indication yet known of rocks older than Gabb's Shasta Group in the Coast Ranges. This exception is a mass of extremely crystalline limestone in the Gavilan Range. It would be in vain to look for fossils in this rock at any point yet observed; nor is there evidence that any of the silicified and serpentinized rocks, so characteristic of the metamorphic series in the Coast Ranges are younger than the beds characterized by the *Ancella piochii* of Gabb. Dr. White shows that between these beds and the Chico there is a vast time interval, while I have shown that in spite of the complication of structure occasioned by post-Cretaceous disturbances, the facts can only be explained by the supposition of a widespread upheaval subsequent to the Shasta and antedating both the Chico and a new series which Dr. White places before the Chico, and which we have named the Wallala beds. The characteristic metamorphism must have occurred in this same interval and probably accompanied the upheaval. This upheaval must have far exceeded in intensity that which followed the Miocene, for the metamorphic rocks are in great part utterly shattered, and often form not plicated beds, but chaotic masses recemented by silica and serpentine. The Coast Ranges, then, existed as dry land and doubtless as mountains for a long period before the beginning of the Chico.

The question immediately arises whether the great upheaval which followed the deposition of the *Ancella* bearing beds of the Coast Ranges was purely local or is to be correllated with any known uplift elsewhere. A comparison with the disturbance which raised and altered the Mesozoic beds of the Sierra Nevada naturally suggests itself and is at once seen to be significant. Some years after Meek had determined the Jurassic character of the Mariposa beds, chiefly because *Ancella* "is, so far as is known, entirely confined to the Jurassic rocks," Gabb redetermined a shell which he had previously described as *Suoceraneus piochii*, and which he had found to be peculiarly characteristic of the Shasta Group. He decided that this shell was an *Ancella*, but drew no geological inferences from this change of genus. It seemed to me clear, however, that its geological importance was great; for if *Ancella* is distinctively Jurassic the *Ancella*-bearing beds of the Coast Ranges, or in other words, the metamorphic series, must be Jurassic, while, if this series is Cretaceous, *Ancella* is not confined to the Jurassic even in the State of California, and the Mariposa beds are not necessarily Jurassic. Dr. White fully agreed with me, and moreover, after careful comparison of great numbers of *Ancellas* from the Coast Ranges with Meek's types and with new and better specimens collected by ourselves on the Mariposa estate, he is unable to draw any specific distinctions between them. There is every reason, therefore, to suppose that the upheaval and metamorphism of the Mariposa beds and that of the *Ancella* beds of the Coast Ranges were contemporaneous, and hence, also, that the first upheaval of the Coast Ranges dates at least as far back as the great uplift to which, as Professor Whitney showed, an important portion of the present Sierra Nevada is due. This uplift must have occurred either after the close of the Jurassic, as Professor Whitney supposed, or after the Neocomian; but Dr. White commits himself no further with reference to the age of *Ancella* than to state that it may be not improbably common to the upper Jurassic and the Neocomian. None of the fossils found accompanying it in California are decisive on this point.

On whichever side of the limiting horizon the *Ancella* of California may ultimately prove to belong, it now seems impossible to assign the Coast Ranges to a different mountain system from the Sierra Nevada, and this conclusion is strengthened by the correspondence in the history of the two ranges since the beginning of the Chico. In the Cascade Mountains of Oregon, near Roseburg, we found the foundation of the range made up of granite and metamorphic rocks indistinguishable from those of the California Coast Ranges. These rocks are overlain unconformably by Miocene beds. Dr. White also points out reasons for believing that at one time during the Cretaceous the peninsula of lower California was the line of separation between the Atlantic and Pacific Oceans. It appears to me, therefore, that the Cascades must be regarded as one of the continuations of the united Sierra Nevada and Coast Ranges to the north, structurally as well as topographically, and that the line of uplift marked by Lower California is equally intimately connected with the ranges of Upper California.

With reference to the later formations the evidence, both structural and paleontological, is clear that there is no interruption of sedimentation or of life between the Chico and the Téjon, while the Téjon and the Miocene are, so far as is known, everywhere conformable. Miocene and Téjon fossils also occur in such proximity as to leave no room for an Eocene series between them distinct from the Téjon, while Dr. White regards the paleontological evidence as overwhelmingly in favor of the Tertiary character of the Téjon beds.

The examination of the quicksilver districts, necessarily interrupted by the investigation sketched above, was resumed as speedily as practicable. The Great Western, Great Eastern, and Napa Consolidated mines, of which detailed maps on a scale of 800 feet to the inch were furnished by the geographical division, have all been worked up by Mr. H. W. Turner. I have also visited each of these districts with him and reviewed his results. Mr. Turner has also inspected a great number of abandoned mines and prospects for the purpose of studying their relations to the general geological structure of the quicksilver belt.

Mr. Waldemar Lindgren, who joined me as assistant geologist on December 1, visited Steamboat Springs during the winter for the purpose of making a preliminary collection of rocks, and has since devoted much time to the microscopical lithology of the eruptive and metamorphic rocks occurring in connection with quicksilver. My own time during the winter and spring was largely occupied by accumulated office work and by a visit to Washington. This year, as last, however, not a month has passed in which no field work has been done by my party. Dr. W. H. Melville has been steadily occupied in analyses and experiments connected with the quicksilver work. At the close of the year the whole party is engaged in the study of Steamboat Springs and its neighborhood.

The field work on the quicksilver belt will close this season, and as a great part of the office work is already completed, I hope to have a memoir on this subject ready for publication by the close of the approaching fiscal year.

Very respectfully, your obedient servant,

GEO. F. BECKER,
Geologist in charge.

Hon. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF MR. J. S. CURTIS.

UNITED STATES GEOLOGICAL SURVEY,
UTAH DIVISION,
Frisco, Utah, June 26, 1885.

SIR: I have the honor to report that during the fiscal year 1884-'85 my time was occupied as follows: During the first few months I was still engaged in correcting the proofs and drawings for my report on "The Silver-Lead Deposits of Eureka, Nevada," which has since been issued. Also during a portion of this time, and up to the month of February, I painted and completed a glass model of the Eureka mines for the New Orleans Exposition, which was subsequently exhibited at that place. From February to June I worked in the laboratory of the Survey, preparing a method for the determination of minute quantities of silver, and when this method of determination was completed I wrote a paper on the subject for the Sixth Annual Report of the director.

On the 4th of June, pursuant to orders, I took the field, going to Frisco, Utah, to examine the Horn Silver Mine. This examination was considerably impeded on account of the caving of the mine. It is still being prosecuted, however, with the prospect of better opportunities for study when some workings shall have been completed which will again open the mine.

Very respectfully, your obedient servant,

J. S. CURTIS,
Geologist.

Hon. J. W. POWELL,
Director United States Geological Survey, Washington, D. C.

REPORT OF PROF. O. C. MARSH.

UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF VERTEBRATE PALEONTOLOGY,
New Haven, Conn., July 1, 1885.

SIR: I have the honor to submit the following report of progress in this division during the past year.

In accordance with your letter of general instructions, dated July 1, 1882, I have continued the systematic work of collecting fossils in the West, especially in the regions that promised to yield specimens needed to complete the investigations now in progress.

Two parties spent the last season in exploring the Jurassic beds of Wyoming and met with good success. Large collections of Dinosaurian reptiles and Jurassic mammals have been secured, among which were many new to science.

Another party carried on investigations in the Jurassic deposits near the Arkansas River, in Southern Colorado, where discoveries of much importance weremade.

During the winter important collections of Permian fossils were secured in Texas.

For the greater part of the past year one party has been engaged in exploring the Pliocene deposits of Kansas and Nebraska, where very large collections of fossil mammals have been made.

In the Jurassic of Wyoming two parties are now at work, with every prospect of success, while in Southern Colorado work in the same horizon has been commenced at the localities where important discoveries have previously been made.

The manuscript of the volume on the *Dinocerata* has been sent to the Public Printer, and the other memoirs in preparation have made good progress during the past year.

The monograph on the *Sauropoda*, the huge Jurassic reptiles found in the West, approaches completion, and the ninety plates which illustrate it are nearly all printed.

On the volume relating to the *Stegosauria* satisfactory progress has been made, and also on the others now in preparation.

Very respectfully, your obedient servant,

O. C. MARSH,
Paleontologist in charge.

Hon. J. W. POWELL,
Director United States Geological Survey, Washington, D. C.

REPORT OF DR. C. A. WHITE.

UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF MESOZOIC INVERTEBRATES,
Washington, D. C., June 30, 1885.

SIR: I have the honor to make the following report of the work that has been done in my division during the fiscal year ending June 30, 1885.

On the 3d day of June, 1884, by your direction I proceeded to California for the purpose of making some paleontologic investigations in connection with the work of Dr. G. F. Becker, in charge of the Pacific division of the Survey. This work was confined mainly to the study of the Cretaceous and earlier Tertiary formations of California, and included not only an investigation of the collections that had already been made by Dr. Becker and his assistants, but studies in the field at numerous localities in different parts of the State. The following counties were visited by me in the prosecution of these field studies: Contra Costa, Alameda, San Mateo, Marin, Monterey, Fresno, Mariposa, Butte, and Shasta. The collections which were previously made by Dr. Becker and his assistants, and which I have also studied, were obtained from the following counties in addition to those which have already been named: San Benito, Mendocino, Lake, and Colusa. The results of these studies are largely set forth in Bulletin of the Survey No. 15, lately published.

These results embrace an investigation of the Téjon, Chico, and Shasta Groups of the California State Survey, and, in part, of the auriferous slate series also. Among the important conclusions which I reached from these investigations are the following: (1) The Chico and Téjon groups together form one unbroken series, extending from the Upper Cretaceous beneath, to the Eocene above, both inclusive. (2) The auriferous slate series is, at least in part, equivalent with the Knoxville division of the Shasta group, and is therefore not of Jurassic age, as it has been generally held to be. (3) There is probably a Cretaceous formation in California which has not hitherto been publicly noticed. The strata in question are found exposed in Mendocino County, some thousands of feet in thickness, according to Dr. Becker. I have given them the provisional name of the Wallala group.

Dr. Becker has published the results of the studies which he made in connection with mine in Bulletin No. 19 of the Survey. Our work having been done in direct association during the whole season, we have mutually assisted each other, which I believe has been of material advantage to the work undertaken by us.

After completing this work in California I sailed from San Francisco, on the 1st of September, for Portland, Oregon. From there I proceeded up the valleys of the Columbia, Willamette, and Umpqua Rivers, in company with Dr. Becker, for the purpose of making some comparative studies of the geology and paleontology of those regions. As the results of the investigations in Oregon proved to be mainly geological, they will appear in the publications of Dr. Becker.

At Eugene City, Oregon, I examined the collections of the State University and that of Prof. Thomas Condon. Professor Condon presented to the Survey, through me, some fossils which he had collected in different parts of Oregon, and which proved to be of considerable interest with relation to certain subjects which I have had under investigation. Some results of the study of these fossils are contained in Bulletin No. 18 of the Survey.

Parting with Dr. Becker in Oregon I returned to Washington, where I have since been engaged in the study of the fossils which have been sent to the Survey and to the United States National Museum by different persons. A part of the results of the study of these fossils appear in Bulletin No. 22 of the Survey and other results are to follow in other bulletins.

A considerable portion of my time has also been employed in the routine work of my division and in the study and determination of fossils for other parties of the Survey.

During the past fiscal year I have prepared the following publications, which contain results of my geological and paleontological studies: Bulletins of the Survey Nos. 15, 18, and 22; articles XXIX and

XXXVI, Vol. XXIX (third series), American Journal of Science, and an address before the Washington Biological Society.

From August 6 to September 4, inclusive, Mr. J. B. Marcou visited the collections of the American Museum of Natural History in New York and of the Academy of Science in Philadelphia and he also made collections of fossils from the Cretaceous and Tertiary formations of New Jersey. During the remainder of the year he has been engaged, aided by the other members of my division, in arranging the collections at the United States National Museum and in the preparation of catalogues and bibliographical material bearing upon the subjects which are under investigation in my division.

Mr. Lawrence C. Johnson has been engaged during the year in making collections in the States of Mississippi, Alabama, and Florida, and the collections which he has forwarded have been received at the United States National Museum.

Mr. Frank Burns, who was assigned to my division in October, was engaged in collecting fossils in Mississippi and Alabama up to the middle of January, 1885. In accordance with instructions, he reported to me at the National Museum on the 22d of January, and he has since been engaged in assorting the collections which he and others have made in the Gulf States.

Mr. C. B. Boyle was detailed for duty in my division, and began work on the 26th of November, 1884. He has been employed mainly in the preparation of catalogues of fossils and bibliographic data.

Respectfully submitted.

C. A. WHITE,
Paleontologist.

Hon. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF MR. C. D. WALCOTT.

UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF PALEOZOIC INVERTEBRATES,
Washington, July 1, 1885.

SIR: In conformity with the request contained in your letter of February 3, 1885, I have the honor to present the following report of operations conducted under my charge during the fiscal year ended June 30, 1885.

The principal field investigations were: The continuation of the taking of sections of the Devonian strata in Western New York, Northwestern Pennsylvania, and Eastern Ohio, and the collecting of fossils from each of the forty-four measured sections. Collections of Cambrian fossils were made in Western Vermont, Western Wisconsin, Eastern Minnesota, Northern Alabama, and Central Texas. A geological section was obtained of the Cambrian system in Llano County, Texas, and an examination was made of the Deer Creek coal-field of the San Carlos Indian Reservation, Arizona.

Prof. Henry S. Williams continued his study of the Devonian sections and faunas of Central and Western New York, Northwestern Pennsylvania, and Eastern Ohio during the months of July, August and September. Collections of fossils were made and sections taken by him at six localities in Sullivan and Orange Counties; at seven, in Chautauqua County; at five, in Otsego and Brown Counties, New York; at fifteen, in Erie, Crawford, and Warren Counties, Pennsylvania; at eleven, in Lake, Geauga, Cuyahoga, and Summit Counties, Ohio: a total of forty-four stratigraphic sections and forty-four collections of fossils.

At the laboratory of Cornell University the collections have been studied and the sections worked out with relation to the contained faunas. Professor Williams has also studied some of the material for the purpose of preparing a paper on the "Plasticity of forms in relation to the geological range and geographical distribution of species."

During the months of July, August, September, and October Mr. Cooper Curtice, paleontological assistant, made extensive collections of fossils from Central and Western Wisconsin and Eastern Minnesota, besides taking notes on the geologic sections and geographic and stratigraphic distribution of the Potsdam or Upper Cambrian fauna. Mr. Curtice's collections embraced thirty barrels and seventeen boxes of specimens that add materially to our collections, and will give much valuable data in studying the Potsdam fauna.

Mr. A. M. Gibson was employed during the months of April and May in continuing the collecting of fossils from the Knox shales of Northern Alabama. He met with good success and sent in valuable material for the illustration of the Upper Cambrian fauna in its southern extension along the Appalachian range.

Mr. S. W. Ford, of New York, was employed as a paleontologic field assistant from December 1, 1884, to June 30, 1885. During the inclement weather Mr. Ford prepared drawings of the type specimens of the Middle Cambrian fauna in his collection and also traced a map of Columbia County, New York, for field use. He has also done some field work in the county named and collected fossils from the Middle Cambrian strata.

Early in July I proceeded to Franklin County, Vermont, for the purpose of studying the Cambrian strata and collecting fossils and tracing the Cambrian strata south into New York State. A large collection was made at Parker's quarry, Georgia, Vermont, and a few sections had been taken when I was recalled to Washington and ordered to report to the honorable the Secretary of the Interior. By him I was appointed a commissioner, in association with a commissioner from civil life, to examine and report upon a coal field in the southern portion of the San Carlos Indian Reservation, Arizona. The examination was completed September 8, 1884, and, acting under instructions from you, I proceeded to Burnet, Texas, and began the examination of the area of Paleozoic rocks in Burnet, San Saba, and Llano Counties. These were found to be composed of Carboniferous, Lower Silurian, Upper Cambrian, and a series of strata called the Llano group, corresponding to the Grand Cañon and Chuar groups of Northern Arizona. A good series of fossils was collected from the Upper Cambrian or Texas-Potsdam group.

I returned to Washington October 14, and at once took up the study of the Middle Cambrian faunas, and also attended to the completion of the publication of Monograph VIII, Paleontology of the Eureka District, and Bulletin 10, Preliminary Studies of the Cambrian Faunas of North America. Both of these publications were completed in December, 1884, and a few copies secured, but owing to unavoidable delays the main edition was not delivered until April, 1885.

The preparation of a bulletin on the Middle Cambrian faunas has occupied all the time not given to incidental work of the office or to work in connection with the identification of collections for the geologists of the Survey and the material sent to me as honorary curator of Paleozoic invertebrate fossils of the National Museum. A collection brought in by Dr. A. C. Peale, of the Survey, was of special interest, as it proved the existence of a well-marked Devonian fauna in Northern Montana. Twenty-three species were distinguished, twelve of which are identical with species of the Upper Devonian of the Eureka district of Central Nevada.

A number of small collections of Carboniferous fossils from Colorado were identified, and lists of the same were furnished to Mr. George H. Eldridge, of the Survey.

A report on the examination of the coal-field of the San Carlos Indian Reservation was prepared during the month of November and transmitted to the honorable the Secretary of the Interior November 28, 1884.

Finding it necessary to obtain some additional data in connection with the study of the Middle Cambrian faunas, I spent a few days, in May, at Swanton, Vermont, and also visited and examined the collections of the Geological Survey of Canada at Ottawa. Through the courtesy of Dr. A. R. C. Selwyn, director of the Canadian Survey, and Prof. J. F. Whiteaves, paleontologist, a number of typical specimens were loaned to me for illustration, and twenty species were procured for the National Museum collections. The material thus obtained has been of great service in the identification of species from Vermont.

A short paper was prepared and published in the American Journal of Science, on the "Paleozoic Rocks of Central Texas," to call attention to the Upper Cambrian and pre-Upper Cambrian strata and their close resemblance to the corresponding geologic formations in the Grand Cañon of the Colorado in Northern Arizona.

The bulletin on the Middle Cambrian Faunas is transmitted for publication this day. It comprises a review of all the species known to me to occur at that horizon in the United States and Canada.

As honorary curator in charge of the collections of the invertebrate Paleozoic fossils of the U. S. National Museum, I gave attention, at various times during the year, to the arrangement of the collections, and a large amount of material collected by the Geological Survey has been labeled and transferred to the Museum. This includes the invertebrate fossils of the Carboniferous system in Central Nevada, exclusive of corals.

The collection contained—

	Species.	Specimens.
Brachiopoda	38	941
Lamellibranchiata	42	445
Gasteropoda	11	72
Pteropoda	3	11
Cephalopoda	5	17
Crustacea	1	11
Poecilopoda	1	140
Total	101	1,637

A full list of the collection was transmitted in my report for the month of December, 1884.

The director of the U. S. National Museum has continued to give every facility for the advancement of work in this office, and I have availed myself freely of the assistance required.

Mr. Cooper Curtice has had charge of the preparatory work on the collections, and has rendered most efficient service in preparing for study the various collections of the Middle Cambrian fossils and those of the Upper Cambrian from Central Texas.

Mr. J. W. Gentry was left in charge of the office during the field season of 1884, and has been occupied at various duties connected with the writing out of manuscript notes on the type-writer, the preparation of catalogues of specimens, proof reading, etc.

Mr. M. T. Burns was detailed, the latter half of the year, to assist in the unpacking and recording of specimens.

The following publications, made on results of studies, carried on in this division, appeared during the year:

Bulletin of the United States Geological Survey No. 3, "On the Fossil Faunas of the Upper Devonian along the meridian of 76° 30′, from Tompkins County, New York, to Bradford, Pennsylvania," by Henry S. Williams, 8vo., 35 pp. 1884.

Publications by the writer:

"Note on Paleozoic Rocks of Central Texas." Am. Jour. Sci., Vol. XXVIII, pp. 431–433. December, 1884.

"Deer Creek Coal-field, White Mountain Indian Reservation, Arizona. Report and Appendix." U. S. Senate Ex. Doc. No. 20, 48th Congress, 2d session, pp. 1–7. December, 1884.

"Bulletin No. 10, United States Geological Survey; on the Cambrian Faunas of North America," pp. 55, Pls. 10, figs. 91.

"Monograph VIII: Paleontology of the Eureka District," pp. i–xiii, 1–298, Pls. 24, figs. 570. 1884.

"Paleozoic Notes: List of Species from the St. John Group, and New Genus Brachiopoda, Linnarssonia." Am. Jour. Sci., Vol. XXIX, Art. xviii, pp. 114–117. February, 1885.

"Paleozoic Notes: New Genus of Cambrian Trilobites, Mesonacis." Am. Jour. Sci., 3d ser., Vol. XXIX, Art. xliii, pp. 328–330, figs. 2. April, 1885.

Very respectfully, your obedient servant,

CHARLES D. WALCOTT,
Paleontologist.

Hon. J. W. POWELL,
Director United States Geological Survey, Washington, D. C.

REPORT OF DR. W. H. DALL.

UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF CENOZOIC INVERTEBRATES,
Washington, D. C., June 30, 1885.

SIR: I have the honor to submit the following report of work done during the year under my direction, according to your instructions, in the division of Quaternary paleontology and related recent forms. I was placed in charge of this work September 20, 1884, and Dr. R. E. C. Stearns was assigned to the division as assistant in the work. Mr. J. B. Crowe was added to the force November 21, 1884.

The condition of affairs on taking up the work was about as follows: The collections already in the possession of the Survey and of the National Museum were very large, but, owing to the want of any one who could give his undivided attention to administering upon them as they came in, they were in very much the same state as when they were originally received. Many of them were packed up, few were catalogued, fewer still had permanent labels. It may safely be said that the arrears of six years had accumulated. Beside these several large collections of the greatest importance for the study of our Quaternary fossils had been just acquired by the National Museum, that of Dr. Gwyn Jeffreys, with a fine series of the English crag fossils, the fossils of the northern drift in Europe, and the crag of Iceland, beside an unparalleled series of the recent forms. Another series, unquestionably the finest in existence for the western American region, that of Dr. Stearns, was just at hand in its original packages. For administering on this mass there were required trays, glass tubes, and receptacles literally by the thousand.

The New Orleans Exposition and the expenditure necessary for the display made by the National Museum and the Geological Survey enabled us to obtain for the department material which could be made useful, not only for the exhibition, but later for the permanent collection. The National Museum, in which the specimens are deposited, contributed to the extent of our more pressing needs in these directions.

The Quaternary fossils of North America are geologically important, especially in two directions. These are the land and fresh water forms of the ancient lake basins of the West and the loess of the Mississippi Valley, and, second, the marine forms for the southern and southeast portions of the United States bordering on the sea. My plan of work, therefore, subject to your approval was to put into shape, for ready reference and the identification of whatever species may come in, the specimens relating to these two areas. This is an indispensable prerequisite to any satisfactory work on the fossils referred to.

Nothing can be done in the way of general paleontological work on our Quaternary formation until this has been accomplished. It is in a certain sense drudgery of a scientific kind, but the familiarity thus gained with the different forms will have its own value in the studies of the future. A large number of assistants, unless skilled in the work (and such unfortunately are not to be had, except in very small numbers), would not proportionally increase the rapidity of our progress. All of it has to be supervised and revised, and this is as much as Mr. Stearns and myself can do at present rates of progress. For more satisfactory co-operation, Mr. Stearns has been assigned the land and fresh-water groups, on which he had already bestowed much study, and I have been at work on the marine forms of the southern and Gulf coasts and the shores of Florida, which have engaged my attention for some years. Mr. Crowe has rendered efficient help in cataloguing and registering specimens, and some 6,400 specimens or lots of specimens have been finally registered and about 8,000 labeled since the work began. Three or four times that number, put into tubes and rendered safe from damage and loss of identification, have been subjected to preliminary determination.

The literature of the subject being much scattered and nowhere brought together, I have begun a bibliography for the southern and southeastern region, to bring all titles of species and place of publication together in a form for ready reference. About twelve thousand entries have already been made for the region between the north shore of Brazil and Cape Hatteras, which forms one zoölogical region. This has been done in the form of a card catalogue and already approaches completion. When finished, I trust it may be found worthy of publication, as it will without doubt form a very useful reference list for all students of the invertebrate paleontology of the region. A summary of the quarternary land and fresh-water species of Alaska, based on my own collections in that region now in the national collection, is in progress, but has been delayed by the necessary work in other directions.

During the last year several small lots have come in and been referred to my department by the office for immediate determination. These comprised some invertebrate remains from various quarters and some vertebrates, especially from the western side of the continent, which have been reported on from time to time.

The services of Mr. Stearns were called into requisition during the installation of the departmental exhibit at New Orleans, so that he was taken away from the regular work for several weeks. Mr. Crowe has been permitted fifteen days' leave of absence during the past month. I was called upon under your instructions to visit the locality of certain vertebrate remains in Alachua County, Florida, which appeared to be of unusual interest. This occupied my time from April 1 to April 19, and the results of the expedition have already been reported upon by me in a special communication under date of May 4, 1885. A certain publication on the land and fresh water shells of the United States, by Mr. W. G. Binney, was undertaken by the National Museum. This work will be of importance for any one engaged in the study of the Quaternary forms of pulmonata. Owing to Mr. Binney's delicate health and distance from the Government Printing Office, it became necessary to have the proofs revised by some one conversant with the subject matter of the work. At the request of Professor Baird, and with our mutual aquiescence, Mr. Stearns assisted Mr. Clarke, of the National Museum, in the revision now completed. This work occupied a good deal of time for two months, but on account of its general importance the time was well spent. The types upon which the book is founded, which have been presented by Mr. Binney to the Museum, will form part of the collection under my charge, and materially assist in the identification of fossils belonging to this group.

It will be seen by the above exhibit that the time of the individuals engaged on the general work included under my division has been fully occupied. In order that such progress could be made I have myself devoted, at the laboratory and in my own workroom, an average of nine hours a day to administration and study since I undertook the work. Much of what has been accomplished makes but little show to the casual visitor, but will be apparent later on.

This department, in common with nearly every other connected with the Survey and the National Museum, though afforded by the authorities of the latter the best facilities at their disposal, has suffered greatly for want of room. This need will be even greater in the near future, and it is to be hoped that quarters for the proper arrangement and exhibition of the treasures of the collection may be soon provided.

I have the honor to be, very respectfully, yours.

WM. H. DALL,
Paleontologist U. S. Geological Survey.

Hon. J. W. POWELL,
Director United States Geological Survey, Washington, D. C.

REPORT OF MR. L. F. WARD.

UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF PALEOBOTANY,
Washington, D. C., June 30, 1885.

SIR: I have the honor to submit the following report of the operations of the division of paleobotany during the fiscal year.

The principal work of the division has been the study and illustration of the two large collections made by myself in the years 1881 and 1883. Most of my own time has been spent in selecting the types from these collections and preparing them for illustration. This involved a prolonged study of several tons of material, the arrangement of the specimens in systematic order, and months of labor with the hammer and chisel, often upon very hard sandstone rock, in working out leaves, fruits, and twigs, of which only small portions were disclosed in the specimens as originally taken from the beds. In this manner no less than 1,056 types have been selected, catalogued, and numbered. These have been separated from the rest of the material and arranged in numerical order in drawers by themselves for the convenience of the draftsmen and for ready reference. There are included among these types a few specimens collected by Messrs. Cross and Emmons at Golden, Colorado, a larger number sent me by Dr. Peale from along the line of the Northern Pacific Railroad in Dakota and Montana, and also much fine material collected in 1882 by Dr. White on the Lower Yellowstone from the same beds in which I obtained my largest collections in 1883.

This work of preparing the types was completed by the end of February of the present year, and since that time I have been chiefly occupied in endeavoring to complete their identification by the aid of figures prepared in the office.

Ensign Everett Hayden, U. S. N., who was then assigned to duty at the National Museum, had devised a system by which the work of illustration could be greatly facilitated through photography. Though still suffering from his serious injury the previous season and unable to remain in Washington, he had succeeded during the spring and summer of 1884, in preparing a number of enlarged drawings, which, however, I was unable to use to any advantage in the study of the types. On October 6 Mr. Hayden was ordered by the Navy Department to duty at the astronomical observatory in Cambridge, Massachusetts, and I was left entirely without a draftsman. On the 27th of that month Miss Annie S. Moorhead was assigned to my division in that capacity, but as she was wholly without experience in that branch of work the progress made was slow and unsatisfactory. When, therefore, Mr. Hayden informed me in December that he had become satisfied that the duty to which he had been assigned at the observatory was incompatible with the preservation of his health and expressed a desire to return to his former post, I gladly seconded his effort and welcomed his restoration, on the 16th of that month, to his former duty as illustrator of fossil plants. Assisted by Miss Moorhead, and with the co-operation of the photographic division of the Survey, he has pushed this department of the work rapidly forward, until at the present time four hundred drawings are completed and ready for the engraver.

The great necessity was first for figures of natural size which could be used in the study of the specimens. The drawings by our method are always enlarged, and are, therefore, not available for this purpose. It was at first proposed to have photo-engravings made as fast as the drawings were completed, and to use proofs of these as aids to study; but this method was found objectionable, because it required the drawings to be completed prior to identification, whereas it constantly happens that improvements can be made in them during the progress of study and as a consequence of it. This system was therefore discontinued and a new plan was devised which obviates both these objections. This method consists in reducing the drawings to their natural size by photography, and in using the photographs from the drawings as aids to study. The result has proved satisfactory in all respects, and by arranging the drawing in large groups, often thirty or forty in a group, the photographic work is reduced to a minimum. By having several impressions of these groups it is found that they can be utilized to great advantage.

My plan of work may be simply stated: One set of the photographs is cut up into independent figures, which are mounted on cards and arranged in the numerical order of the types for reference in cases where the number is known. A second set of the groups of figures is mounted intact upon large card-boards, which are suspended from a revolving cylinder devised for the purpose. This is found to be the main dependence when making comparisons with the figures of fossil plants published in the numerous illustrated works on the subject, which comparison constitutes the principal labor in the identification of species. One or more reserve sets are left unmounted for exchange or for other purposes, and if more are needed blue prints are made without further tax upon the photographer. For all these and many other ingenious devices which need not be named here, but which greatly facilitate research, I am chiefly indebted to the fertile mind of Mr. Hayden, whose invaluable assistance it gives me great pleasure thus publicly to acknowledge.

On the 3d of February I received an official invitation to prepare a contribution to the Sixth Annual Report of the Survey for the years 1884–'85. As most of my collections have been from the Laramie Group, as I understand its limits, and as my report upon those collections will be so large that all general considerations will probably be crowded out of it, I thought that such a paper would afford an opportunity to offer some discussion of the facts observed by myself and to collect into compact form the leading points that have been dwelt upon by others in relation to the flora of this group. As such a paper must be to some extent a compilation and aim to give a synthetic view of the subject of this now celebrated flora, the details of which are scattered through scores of volumes of scientific journals and official reports, it seemed to me that the paper might be properly entitled a "Synopsis of the flora of the Laramie Group." Such a paper I have undertaken to prepare, and it is herewith submitted. In addition to such general discussions, tabular exhibits, and digest of the literature, as above indicated, I have introduced some descriptive matter derived from my field notes and from specimens of peculiar interest collected by myself, which latter will be illustrated by from thirty to thirty-five plates. It will not, however, constitute in any sense a descriptive paper, and the figures, though they will be accompanied by names, provisional at least, are only introduced for the purpose of illustrating the general character of the Laramie flora as I found it.

Although the force of the division has been chiefly employed and its energies have been concentrated upon the scientific department as above outlined, there has been no relaxation in my efforts to push forward the work upon the proposed "Compendium of Paleobotany," a rough draft of the contents of which was given in my last administrative report. This branch of the work was necessarily interrupted during three months of the year, from October 1, 1884, to January 3, 1885, when it was resumed upon the employment of Mr. Bruno Müller. His first work was to complete the slip index of species so far as the works in hand were concerned. This work has been done in a very satisfactory manner, and as the sub-library which I have collected from various sources embraced most of the principal systematic works on the subject, this index, now consisting of between 35,000 and 40,000 slips, each slip referring directly to the page, plate, and figure where the species is published, and all arranged in strictly alphabetical order and placed in drawers fitted up for this express purpose, constitutes a most efficient aid to my researches. It is of course still incomplete, many works, some quite important and some very recent, not having yet come into my possession and I am now making every effort to secure these works. Within the last month Mr. Müller has prepared a large list of the titles of such works, and this has been placed in the hands of Mr. George H. Boehmer, in charge of the international exchanges of the Smithsonian Institution, who has special facilities for securing them in exchange for the publications of the Institution and those of the National Museum and the Geological Survey, and who has kindly offered to ascertain the prices and mode of securing such as cannot be obtained otherwise than by purchase.

Before proceeding further with the work of cataloguing species it has been thought best to complete the list of titles of all works on fossil plants, so far as such titles can be secured, and within the past ten days Mr. Müller has commenced work upon this branch of the subject.

I greatly regret the delay in the preparation of this important manual, but unless work upon it is again suspended I see no reason to doubt that the manuscript will be ready by the close of the next fiscal year.

In my capacity as an honorary curator for the National Museum I have, with the co-operation of the director and the assistant director of the Museum, been conducting during a considerable portion of the year a series of operations which are of the highest importance to my paleontological work, but which I have not thus far reported to you because they more properly belonged to my reports as curator. It is, however, proper that the character of this work should be made known to you and its direct bearing upon the work of the Geological Survey be pointed out.

The value of all work in paleobotany must depend entirely upon the correctness of the determinations of the plant remains which are found in the rocks. These determinations are admitted to constitute the most difficult branch of paleontological science. Those who have attained to any high degree of proficiency are often spoken of as possessing something beyond the ordinary measure of human judgment. While admitting that the masters in this difficult science have been men of extraordinary powers of observation and comparison, I have become convinced, from a protracted study of their works, that these qualities would have availed them little had they not had at the same time access to an exceedingly wide range of material for their exercise. Fossil plants can only be identified by comparison with living plants, and the more extensive the collections of the latter the more trustworthy will be the determinations of the former if faithfully made.

From the outset of my investigations in this department four years ago I have been deeply impressed with the great need of more extensive collections, and of having such as exist in greater proximity to the department of fossil plants, and I thus early commenced urging upon the Museum authorities the necessity of establishing within the Museum a department of botany and an herbarium. As you are aware, by an arrangement effected many years ago, all botanical collections belonging by law to the Museum were deposited with the Commissioner of Agriculture. I urged that this custom be discontinued, but practical questions as to space and cost delayed action, although the Museum authorities were antecedently disposed to this course. I was several times consulted as to the probable expense and the proper person to select as curator of botany, but up to the close of the last fiscal year nothing had been done further than to hold certain collections, notably a very large one which had been received from the herbarium at Kew. I finally made the proposition that on condition that the herbarium be located in immediate proximity to the department of fossil plants I would undertake to perform the duty of curator, provided a suitable assistant be assigned me; and I further offered to contribute my own collection of plants, consisting of about 5,000 species and 15,000 specimens, as a nucleus for the herbarium. This proposition was accepted, and as soon as space could be provided steps were taken in this direction. On February 2, 1885, my herbarium was removed to the Museum, and shortly afterwards the collection from the Kew herbarium was transferred to my charge.

Early in November two assistants, Mr. Frank H. Knowlton and Mr. A. L. Schott, employés of the National Museum, were assigned to the departments of botany and fossil plants to assist in the previously much neglected work connected with the curatorship, which I had found it impossible to perform in connection with my duties for the Geological Survey. These gentlemen are still under my charge and have performed a very large amount of important work, chiefly of a scientific character. Mr. Knowlton is an efficient botanist, and I have found it possible to entrust to his charge nearly all the duties incident to the curatorship. Mr. Schott came to the Museum from the Botanic Garden to take charge of the palms and other ornamental plants that were transferred from there and placed in the rotunda of the Museum, the whole of which matter naturally fell under my department. Taking advantage of his familiarity with the public gardens and parks of the city, I have assigned to Mr. Schott the duty, among others, of making collections of specimens from all the trees, shrubs, and other plants growing within the limits of Washington, including such green-houses as were accessible. With the permission of the several authorities in charge of these inclosures he has made extensive collections of this nature, greatly enriching the herbarium and increasing its usefulness as an aid to the identification of fossil plants. By these and all other available means I hope eventually to possess the facilities to the help of which the great success of certain celebrated investigators in Europe is so largely due.

Very respectfully, your obedient servant,

LESTER F. WARD,
Geologist.

Hon. J. W. POWELL,
Director United States Geological Survey, Washington, D. C.

REPORT OF PROF. WILLIAM M. FONTAINE.

UNITED STATES GEOLOGICAL SURVEY,
Noel's Post-office, Virginia, June 18, 1885.

SIR: I have to report that during the months of May and June of the past year I was engaged in making a preliminary examination of the belt of Younger Mesozoic strata extending from Fredericksburg to Washington City. In August and September I hired a wagon and team, and taking camp equipment, proceeded, while camping out, to make a detailed examination of the same belt. My examination covered the entire belt from Fredericksburg, Virginia, to Washington. This, with previous examinations made of the strata of the same age extending from Petersburg by Richmond to a point in Caroline County, Virginia, enabled me to make a report covering the whole of the Younger Mesozoic formation in the State of Virginia. For the details of the results obtained reference is made to the report, which some months ago was forwarded to you. In the course of my examination new and important localities affording plant fossils were found and considerable collections were made, which add much to the value and interest of the fossils previously obtained.

When not employed in the field work above mentioned, such time as was not occupied by my professional duties was bestowed on the study and drawing of the considerable amount of fossil plants collected from time to time.

This material will furnish a large and important addition to our knowledge of the plant life of a formation that is as yet almost a blank with respect to its paleobotany.

Very respectfully,

WM. M. FONTAINE,
Paleontologist.

Hon. J. W. POWELL,
Director United States Geological Survey, Washington, D. C.

REPORT OF PROF. F. W. CLARKE.

UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF CHEMISTRY AND PHYSICS,
Washington, July 1, 1885.

SIR: I have the honor to submit the following report of work done in the division of chemistry during the fiscal year 1884–'85.

At the close of the preceding fiscal year our laboratory force in Washington consisted of Dr. F. A. Gooch, Dr. T. M. Chatard, two laborers, and myself, and we still occupied the comparatively small suite of rooms on the second floor of the southwest pavilion of the National Museum. On the 1st of August Mr. J. Edward Whitfield was added to our corps of analysts, and on the 1st of March Mr. R. B. Riggs was also appointed. The force now at work in our chemical laboratory consists, therefore, of five chemists and two laborers.

Early in October, in consequence of the removal of the Survey offices to the Hooe buildings, the rooms in the northeast pavilion of the Museum became vacant. These rooms, twelve in number, were then placed at the service of this division, and as quickly as possible nine of them were fitted up for laboratory purposes. The three rooms upon the ground floor, one large and two small, were assigned to the physical laboratory; which, still in charge of Drs. Carl Barus and William Hallock, was moved from New Haven to Washington in November. The room on the second floor, formerly used as a library, was equipped as a workshop and furnace room, while the four remaining rooms upon the same floor were fitted up as a general chemical laboratory. On the third floor one room was also arranged as a laboratory, one was taken as a storage room, and two others remain in partial use, to be devoted hereafter to special lines of chemical investigation. With the equipment of the latter our laboratory will become practically complete.

The work of the division during the year has necessarily been very varied. In the first place, a large number of routine analyses have been made, mainly with reference to the work of the field geologists. A list of these analyses would obviously be out of place in this report, so that a bare indication of their general character must suffice for present purposes. They have included, besides other matters, examinations of coals and iron ores from West Virginia, clays from Wisconsin, waters, travertines, geyserites, and obsidians from the Yellowstone Park, interesting minerals from various localities, volcanic rocks from New Mexico, several mineral waters, a series of maritime soils from Massachusetts, some assays of ores, etc. A few analyses have also been performed for the accommodation of other departments of the Government, such as two samples of paper for the Post-Office Department, two building stones for the Supervising Architect of the Treasury, and so on. The division has also been called upon to identify a considerable number of mineral species.

A second portion of our work has been in the line of original research, and in this direction a good beginning has been made. Throughout the year I have myself been engaged upon investigations, partly in the laboratory and partly theoretical, upon the chemical constitution of the natural silicates and the laws governing their alteration. This work, which was often interrupted by matters of immediate urgency, is still in progress, but some conclusions of value have already been reached. For example, it has been shown that many of the mineral silicates are substitution derivatives of the normal aluminum orthosilicate, a conclusion which helps to explain the genesis of some important rock-forming species. These investigations have been accompanied by some field work, as in August I made a two weeks' trip among the lepidolite localities of Oxford County, Maine, and in September I spent three days among the feldspar quarries of central Connecticut. In both regions I collected valuable material bearing upon the subject of my researches.

Another line of chemico-geological investigation was taken up by Dr. Chatard, relative to the origin of corundum. In August and again in October he visited the corundum mines near Franklin, North Carolina, made collections of material, and took careful notes of the mode of occurrence of the mineral. The samples collected, representing a section of the Corundum Hill locality, have since been under examination in the laboratory, and a valuable suite of analyses has been made.

During the summer, from early July until late October, Dr. Gooch was in the field with Mr. Hague's party. He collected much material relative to the geysers of the Yellowstone Park, and the analytical part of the investigation is still in progress. Dr. Gooch has also done some valuable work during the year in the improvement of analytical processes, and has prepared two papers upon them. One describes a form of soluble filter, the other a method of separating aluminum from titanium. Both processes will be of great service in the future work of the division.

The work done in the physical laboratory of the division has naturally been somewhat interrupted by the removal from New Haven and by the absence of Dr. Hallock during the summer on field duty with Mr. Hague. Progress, however, may be reported in the investigation of high temperatures. Dr. Barus, furthermore, has completed a most valuable research upon the thermoelectric properties of the iron carburets, now in type and ready for publication as Bulletin 14. The new physical laboratory is now in good running order and work in it will be pushed forward rapidly.

Very respectfully,

F. W. CLARKE,
Chemist.

Hon. J. W. POWELL,
Director United States Geological Survey, Washington, D. C.

REPORT OF MR. ALBERT WILLIAMS, JR.

UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF MINING STATISTICS,
Washington, D. C., June 30, 1885.

SIR: I have the honor to report that the work of this division during the fiscal year 1885, ending on this date, has consisted mainly in the preparation of a report on the condition of the mineral industries during the past two calendar years. This report, entitled the "Mineral Resources of the United States, 1883 and 1884," is now in press. It is in continuation of the report for the calendar year 1882, issued in 1883. The following is a summary of the metallic and non-metallic mineral production during the last three years, from which it appears that the total value of the metals and minerals produced in 1884 was $39,100,008 less than in 1883, and that the decline in 1883 from 1882 was $3,012,061; that is, the falling off in value began on a small scale in 1883, but was still more marked in 1884. The net decline, as will be seen by reference to the tables, has been due rather to a depression in price than to a decrease in quantity; indeed, several important substances show a decided increase in production, notwithstanding the general dullness of trade. The overproduction, taking the whole field into consideration, has been less than was generally feared.

Metallic products of the United States in 1884.

	Quantity.	Value.
Pig-iron, spot value .... long tons..	4,097,868	$73,761,624
Silver, coining value .... troy ounces..	37,744,605	48,800,000
Gold, coining value .... do......	1,489,949	30,800,000
Copper, value at New York City (*a*) .... pounds..	145,221,934	17,789,687
Lead, value at New York City .... short tons..	139,897	10,537,042
Zinc, value at New York City .... do......	38,544	3,422,707
Quicksilver, value at San Francisco .... flasks..	31,913	936,327
Nickel, value at Philadelphia (*b*) .... pounds..	64,550	48,412
Aluminum, value at Philadelphia .... troy ounces..	1,800	1,350
Platinum, value crude at New York City .... do......	150	450
Total	....	186,097,599

a Including copper made from imported pyrites. *b* Including nickel in copper-nickel alloy.

Non-metallic mineral products of the United States in 1884 (spot values).

	Quantity.	Value.
Bituminous coal, brown coal, lignite, and anthracite mined elsewhere than in Pennsylvania (*a*) .... long tons..	73,730,539	$77,417,066
Pennsylvania anthracite (*b*) .... do....	33,175,756	66,351,512
Petroleum .... barrels..	24,089,758	20,476,294
Building stone	....	19,000,000
Lime .... barrels..	37,000,000	18,500,000
Salt .... do...	6,514,937	4,197,734
Cement .... do....	4,000,000	3,720,000
South Carolina phosphate rock (*c*) .... long tons..	431,779	2,374,784
Limestone for iron flux .... do....	3,401,930	1,700,965
Mineral waters .... gallons sold..	68,720,936	1,665,490
Natural gas	....	1,460,000
Zinc white .... short tons..	13,000	910,000
Concentrated borax .... pounds..	7,000,000	490,000
New Jersey marls .... short tons..	875,000	437,500
Mica .... pounds..	147,410	368,525
Pyrites .... long tons..	35,000	175,000
Gold quartz souvenirs, jewelry, etc	....	140,000
Manganese ore .... long tons..	10,000	120,000
Crude barytes .... do....	25,000	100,000
Ocher .... do....	7,000	84,000
Precious stones	....	82,975
Bromine .... pounds..	281,100	67,464
Feldspar .... long tons..	10,900	55,112
Chrome iron ore .... do....	2,000	35,000
Asbestus .... short tons..	1,000	30,000
Slate ground as a pigment .... long tons..	2,000	20,000
Sulphur .... short tons..	500	12,000
Asphaltum .... do....	3,000	10,500
Cobalt oxide .... pounds..	2,000	5,100
Total	....	220,007,021

a The commercial product, that is, the amount marketed, was only 66,875,772 tons, worth $70,219,561.
b The commercial product, that is, the amount marketed, was only 30,718,293 tons, worth $61,436,586.
c Year ending May 31.

Résumé of the values of the metallic and non-metallic mineral substances produced in the United States in 1884.

Metals	$186, 097, 599
Mineral substances named in the foregoing table	220, 007, 021
	406, 104, 620
Fire-clay, kaolin, potter's clay, common brick clay, terra cotta, building sand, glass sand, limestone used as flux in lead smelting, limestone in glass making, iron ore used as flux in lead smelting, marls (other than New Jersey), gypsum, tin ore, antimony, iridosmine, mill-buhrstone, and stone for making grindstones, novaculite, corundum, lithographic stone, talc and soapstone, quartz, fluorspar, nitrate of soda, carbonate of soda, sulphate of soda, native alum, ozocerite, mineral soap, strontia, infusorial earth and tripoli, pumice-stone, sienna, umber, etc., certainly not less than	7, 000, 000
Grand total	413, 104, 620

Metallic products of the United States in 1883.

	Quantity.	Value.
Pig iron, spot value ... long tons	4, 595, 510	$91, 910, 200
Silver, coining value ... troy ounces	35, 733, 622	46, 200, 000
Gold, coining value ... do	1, 451, 249	30, 000, 000
Copper, value at New York City (*a*) ... pounds	117, 151, 795	18, 064, 807
Lead, value at New York City ... short tons	143, 957	12, 322, 719
Zinc, value at New York City ... do	36, 872	3, 311, 106
Quicksilver, value at San Francisco ... flasks	46, 725	1, 253, 632
Nickel, value at Philadelphia (*b*) ... pounds	58, 800	52, 920
Aluminum, value at Philadelphia ... troy ounces	1, 000	875
Platinum, value crude at New York City ... do	200	600
Total	....	203, 116, 859

a Including copper made from imported pyrites. *b* Including nickel in copper-nickel alloy.

Non-metallic mineral products of the United States in 1883 (*spot values*).

	Quantity.	Value.
Bituminous coal, brown coal, lignite, and anthracite mined elsewhere than in Pennsylvania (*a*) ... long tons	68, 531, 500	$82, 237, 800
Pennsylvania anthracite (*b*) ... do	34, 336, 469	77, 257, 055
Petroleum ... barrels	23, 400, 229	25, 740, 252
Building stone	....	20, 000, 000
Lime ... barrels	32, 000, 000	19, 200, 000
Cement ... do	4, 190, 000	4, 293, 500
Salt ... do	6, 192, 231	4, 211, 042
South Carolina phosphate rock (*c*) ... long tons	378, 380	2, 270, 280
Limestone for iron flux ... do	3, 814, 273	1, 907, 136
Mineral waters ... gallons sold	47, 289, 743	1, 139, 483
Concentrated borax ... pounds	6, 500, 000	585, 000
New Jersey marls ... short tons	972, 000	486, 000
Natural gas	....	475, 000
Mica ... pounds	114, 000	285, 000
Pyrites ... long tons	25, 000	137, 500
Manganese ore ... do	8, 000	120, 000
Gold quartz souvenirs, jewelry, etc	....	115, 000

a The commercial product, that is, the amount marketed, was only 65,268,095 tons, worth $78,321,714.
b The commercial product, that is, the amount marketed, was only 31,793,027 tons, worth $71,534,311.
c Year ending May 31.

Non-metallic mineral products of the United States in 1883 (spot values)—Continued.

	Quantity.	Value.
Crude barytes .... long tons..	27,000	$108,000
Precious stones	....	92,050
Ocher .... long tons..	7,000	84,000
Bromine .... pounds..	301,100	72,264
Feldspar .... long tons..	14,100	71,112
Chrome iron ore .... do....	3,000	60,000
Graphite .... pounds..	575,000	46,000
Asbestus .... short tons..	1,000	30,000
Sulphur .... do....	1,000	27,000
Slate ground as a pigment .... long tons..	2,000	24,000
Asphaltum .... short tons..	3,000	10,500
Cobalt oxide .... pounds..	1,096	2,795
Total	....	241,087,769

Résumé of the values of the metallic and non-metallic mineral substances produced in the United States in 1883.

Metals	$203,116,859
Mineral substances named in the foregoing table	241,087,769
	444,204,628
Estimated value of mineral products unspecified	8,000,000
Grand total	452,204,628

Metallic products of the United States in 1882.

	Quantity.	Value.
Pig-iron, spot value .... long tons..	4,623,323	$106,336,429
Silver, coining value .... troy ounces..	36,197,695	46,800,000
Gold, coining value .... do	1,572,186	32,500,000
Copper, value at New York City (*a*) .... pounds..	91,646,232	16,038,091
Lead, value at New York City .... short tons..	132,890	12,624,550
Zinc, value at New York City .... do......	33,765	3,646,620
Quicksilver, value at San Francisco .... flasks..	52,732	1,487,042
Nickel, value at Philadelphia (*b*) .... pounds..	281,616	309,777
Antimony, value at San Francisco .... short tons..	60	12,000
Platinum, value crude at New York City .... troy ounces..	200	600
Total	....	219,755,109

a Including copper made from imported pyrites. *b* Including nickel in copper-nickel alloy.

Non-metallic mineral products of the United States in 1882 (spot values).

	Quantity.	Value.
Bituminous coal, brown coal, lignite, and anthracite mined elsewhere than in Pennsylvania (*a*) ......long tons..	60,861,190	$76,076,487
Pennsylvania anthracite (*b*) ......do....	31,358,264	70,556,094
Crude petroleum (*c*) ......barrels..	30,053,500	23,704,698
Lime ......do....	31,000,000	21,700,000
Building stone	....	21,000,000
Salt ......barrels..	6,412,373	4,340,140
Cement ......do....	3,250,000	3,672,750
Limestone for iron flux ......long tons..	3,850,000	2,310,000
South Carolina phosphate rock (*d*) ......do....	332,077	1,992,462
New Jersey marls ......short tons..	1,080,000	540,000
Concentrated borax ......pounds..	4,236,291	338,903
Mica ......do....	100,000	250,000
Natural gas	....	215,000
Ocher ......long tons..	7,000	105,000
Soapstone ......short tons..	6,000	90,000
Crude barytes ......long tons..	20,000	80,000
Precious stones	....	75,000
Gold quartz souvenirs, jewelry, etc	....	75,000
Pyrites ......long tons..	12,000	72,000
Manganese ore ......do....	3,500	52,500
Chrome iron ore ......do...	2,500	50,000
Asbestus ......short tons..	1,200	36,000
Graphite ......pounds..	425,000	34,000
Cobalt oxide ......do....	11,653	32,046
Slate ground as a pigment ......long tons..	2,000	24,000
Sulphur ......short tons..	600	21,000
Asphaltum ......do....	3,000	10,500
Corundum ......do....	500	6,250
Pumice-stone ......do....	70	1,750
Total	....	227,461,580

a The commercial product, that is, the amount marketed, was only 57,963,038 tons, worth $72,453,797.
b The commercial product, that is, the amount marketed, was only 29,120,096 tons, worth $65,520,216.
c Pennsylvania and New York field only; the outside production was very small.
d Year ending May 31.

Résumé of the values of the metallic and non-metallic mineral substances produced in the United States in 1882.

Metals	$219,755,109
Mineral substances named in the foregoing table	227,461,580
	447,216,689
Estimated value of mineral products unspecified	8,000,000
Grand total	455,216,689

In addition to the purely statistical work of this division, information regarding the occurrence and utilization of the mineral products has been furnished by correspondence in reply to numerous inquiries.

The office force has consisted of Mr. W. A. Raborg and myself, with occasional clerical assistants. The collection of statistics and preparation of technical and descriptive matter have been carried on in this office, but more largely by my agents and correspondents in various parts of the country, to whose public spirit and cordial co-operation I am largely indebted.

Very respectfully, your obedient servant,

ALBERT WILLIAMS, JR.
Geologist in Charge.

Hon. J. W. POWELL,
Director United States Geological Survey, Washington, D. C.

REPORT OF MR. GEORGE W. SHUTT.

UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF FORESTRY,
Washington, D. C., *June* 30, 1885.

SIR: I have the honor to submit a brief statement of the operations of the forestry division of the Survey for the year ending June 30, 1885.

In accordance with your directions, I have made during the last two years a careful inspection, traveling by wagon and on horseback, of the least known regions of the Appalachian range embraced within the limits of Virginia and West Virginia.

I also addressed a series of questions to selected citizens in the two States respecting the forest distribution of the counties of their residence, the kinds of trees by districts, and the names and situation of streams and mountains. Besides the reports transmitted referring to the trees of the districts concerned, there were received in response to the inquiry last named, sketches and partial maps of over forty counties not heretofore mapped and generally unknown. From many other counties not mapped trustworthy information respecting forest distribution was received, and from all, including those mapped, a statement of existing facilities for the transportation of logs and lumber by streams not navigable to railroads or navigable waters.

I do not undertake at this time to give the correct location of all the forest districts in the counties concerned, this being a part of the work that must necessarily be deferred until a satisfactory map of each State shall have been completed.

The average stumpage value of such forest products accessible to markets as are classified by the statements and estimates received exceeds, according to the best information attainable, $4 a thousand feet, and the value of the product in the markets of the world would be more than four times as great. In the State of West Virginia alone the value of the standing timber at this rate amounts to $447,000,000.

I purpose to embody the results of my investigations in a paper, accompanied by full statistical details, which I shall shortly submit for publication as a bulletin by the Survey.

I am, very respectfully, your obedient servant,

GEORGE W. SHUTT,
Chief of Forestry Division.

Hon. J. W. POWELL,
Director United States Geological Survey, Washington, D. C.

REPORT OF MR. W. H. HOLMES.

UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF ILLUSTRATIONS,
Washington, July 13, 1885.

SIR: During past years it has been the practice of the Survey to give out a large portion of the work of preparing illustrations to competent draughtsmen not connected with the office. This method seemed to be open to objection, and, acting in accordance with instructions from you, I have, within the fiscal year, selected a number of draughtsmen having especial qualifications for the work who have been regularly attached to the Survey. The results appear to be entirely satisfactory.

It is still occasionally necessary, when there is a pronounced increase in the amount of work called for, to give a portion of it out by contract.

Acting under my personal direction in this office, there are three assistants: Mr. DeLancy W. Gill, who is especially proficient in landscape and panoramic work, as well as in the drawing of all kinds of diagrams and sections; Mr. John L. Ridgway, an adept in all branches of natural history work, especially paleontology; and Mr. Frederick W. von Dachenhausen, who has worked only in paleontology.

Draughtsmen not located in the Survey building are necessarily under the direction of the gentlemen for whom they work. With Mr. L. F. Ward, at the National Museum, are Ensign Everett Hayden and Miss Moorhead, who are engaged largely upon fossil botany. Professor Scudder's assistant, Mr. Blake, prepares the former's drawings of fossil insects, while Professor Marsh has most of his illustrations drawn directly upon stone by the lithographers.

A number of the geologists and paleontologists—Messrs. Fontaine Whitfield, McGee, and others—make their own drawings; and Mrs. R. D. Irving, the wife of Professor Irving, prepares his microscopic plates (a work in which she is unsurpassed) without compensation from the Government.

The methods of reproduction employed include lithography, chromo-lithography, wood engraving, and several photo-engraving processes. Chromo-lithography is rarely used, excepting where artistic coloring is essential or in atlas work. Photolithography is the most economical method for large work, such as panoramas, maps, and sheets of sections. Lithography is employed on special work where other cheaper processes are inadequate. The same may be said of such methods as the heliotype and the artotype, which are excellent in the reproduction of photographic originals where minute details of light and shade must be preserved in *fac simile.* With the exception of photo-lithography, these methods are all expensive and have the additional disadvantage of requiring re-engraving for each new edition called for.

Wood engraving and photo-engraving processes have peculiar advantages for scientific work. They supply plates that may be preserved, and which, by electrotyping, may be multiplied indefinitely. These can be set up with the type or arranged in separate plates, as the author chooses, and are capable of rearrangement with every additional representation or with each varying presentation of the matter to which they pertain, and all of this without additional cost. These are, therefore, strong reasons why one or both of these processes should be made available for a wider and wider range of work.

Photo-engraving is entirely successful within a certain range of subjects, including simpler work of all classes, and where very skillful draughtsmen are employed it can be made to cover a very large field; but in the reproduction of textures and forms where refinement of tint, delicacy of light and shade, and minuteness of detail are essential, wood engraving seems to be the only method having the requisite powers of expression, saving, of course, lithography, which has, however, the fatal failings already mentioned.

Wood engraving is competent to do all that is required, and during the last year a strong effort has been made to reach a higher grade of execution, but there are a number of difficulties in the way of securing the best possible results from this method. To enumerate these difficulties: In the first place engravers are not regularly employed, and the illustrations for each work are given out by contract. They thus fall into the hands of individuals or firms who may or may not have experience in the work. Engravers are selected according to the best judgment of the contractors, but, as a rule, they have little idea of the requirements of scientific illustration, and a large percentage of the figures are ruined or imperfectly engraved before the peculiarities of the work are understood. This tedious process of apprenticeship and experiment, resulting in indifferent success, must be endured with each new contract.

There is also in wood engraving the difficulty of interpretation by the engraver of the forms and textures of the original. If the engraver's judgment is at fault a totally wrong idea may be given of the subject treated. In order to avoid this danger as far as possible, the subjects are no longer drawn directly on the wood, but are transferred to wood by photography, the original photographs or drawings being preserved and kept before the engraver while at his work. They are afterwards used for comparison, criticism, and correction.

The greatest difficulties would be overcome by the permanent employment of skillful workmen, and until this is done the fitness of wood-engraving for scientific illustration can never be properly tested.

Formerly it was very difficult to secure printing of a grade sufficiently high to warrant the preparation of first class wood engraving. This also worked to the disadvantage of the method, but more recently, through the intelligence and enterprise of the Government Printer and his assistants, the printing is greatly improved.

In the preparation of illustrations care is taken to secure a high degree of accuracy. Illustrations are no longer to be treated chiefly as a means of embellishment; they are expected to express facts with a clearness and accuracy not surpassed by the language of the letter press.

With an eye to the future we are endeavoring to secure work of an exceptionally high grade. The best we can do will be in danger of relegation to a second place by the illustrators of the coming generation.

During the year illustrations for the following publications have been transmitted through this office: 3 monographs, 1 annual report, and 11 bulletins. The illustrations for these may be classed as follows:

27 plates by chromo lithography — 7 microscopic petrography; 20 maps.
91 plates by lithography — 56 fossil vertebrates; 35 fossil invertebrates.
14 plates by photo lithrography — maps, charts, diagrams, and sections.
74 plates by wood engraving — 14 fossils; 60 landscapes, etc.
54 plates by photo engraving — 15 fossils; 39 landscapes, sections, etc.
148 figures by wood engraving — landscapes, etc.
101 figures by photo engraving — miscellaneous.

Many of the illustrations included in this list were prepared during preceding years. The following table gives approximately, the drawings executed since June 30, 1884; they belong chiefly to volumes not yet transmitted to the printer.

Fossil mollusca, 950 figures.
Fossil vertebrates, 300 figures.
Fossil insects, 200 figures.
Fossil plants, 767 figures.
Geological landscapes, etc., 20 plates.
Geological landscapes, etc., 45 figures.
Panoramic views, 8 plates.
Charts and maps, 20 plates.
Sections and diagrams, 90 plates and figures.

A large percentage of the illustrations are engraved directly from photographs; these are not included in this list. The methods of reproduction are not determined upon until the copy is prepared for transmission to the Public Printer.

The photographic work of the Survey has been conducted as in previous years by Mr. J. K. Hillers, with Messrs. Jones, Smart, and Searle as assistants.

The gallery has been furnished with an ample skylight and with every facility for the execution of the varied and often difficult work demanded by both the geologic and the topographic corps.

A most important feature of the work consists in the reproduction of topographic maps which must be prepared with accuracy and dispatch for the use of engravers and field parties.

During the year another duty has been imposed upon this division, the photographing of fossil remains. This work presents many difficulties, but by it the palæontologist is enabled to secure greater accuracy than by any other method.

Mr. Hillers has undertaken no field work during the year, but complete dry-plate outfits have been furnished to a number of the field parties, and thus several hundreds of valuable negatives from all parts of the country have been added to the collection. Many of these have been transferred directly to box-wood and are being engraved for the reports of the Survey.

The following list shows approximately the number and size of negatives, prints, and transparencies made during the year:

Negatives.		Prints.		Transparencies.	
Size.	Number.	Size.	Number.	Size.	Number.
28 x 34	145	28 x 34	1,139	28 x 34	145
20 x 24	152	20 x 24	1,151	20 x 24	14
14 x 17	54	14 x 17	408		
11 x 14	84	11 x 14	3,705	11 x 14	12
8 x 10	213	8 x 10	3,135		

Very respectfully, your obedient servant,

W. H. HOLMES,
Geologist.

Hon. J. W. POWELL,
Director United States Geological Survey, Washington, D. C.

REPORT OF MR. CHAS. C. DARWIN.

UNITED STATES GEOLOGICAL SURVEY,
Washington, July 1, 1885.

SIR: I have the honor to transmit to you the following statement of work done in this division during the fiscal year just ended.

The library has benefited greatly by the change to its new quarters. The room which served for accommodation of the infant collection of 1882 was sadly cramped by the rapid increase in the number of books, by the accumulations of the publications of the Survey, and by the growth of the correspondence relating thereto. The removal was carefully planned and made without the loss of a book or paper, during the first week in October, 1884.

The new quarters permit a differentiation of the work of the division into three lines, which relate to the *library* proper, to the *publications* of the Survey, and to the *correspondence* with regard to both of these.

LIBRARY.

During the year the collection of 14,712 books and pamphlets so rapidly acquired before June 30, 1884, has been wholly catalogued by authors, and this relief from arrears of work permits the current increase to be promptly attended to day by day.

That increase, coming in a great measure from scientific exchanges, has, during the year, almost doubled the contents of the library, so that it now has 25,912 volumes and pamphlets.

CONTENTS OF LIBRARY JUNE 30, 1885.

Books.			
On hand June 30, 1884:			
Received by exchange	8,714		
Received by purchase	2,801		
		11,515	
Received during the year:			
By exchange	2,451		
By purchase	746		
		3,197	
Whole number of books			14,712
Pamphlets.			
On hand June 30, 1884:			
Received by exchange	6,400		
Received by purchase	500		
		6,900	
Received during the year:			
By exchange	4,000		
By purchase	300		
		4,300	
Whole number of pamphlets			11,200
Whole number of books and pamphlets			25,912

In this table no notice has been taken of maps for the reason that they can only at present be approximately enumerated. A map room has, however, been set apart for them and the work of entering and classifying them begun. All foreign maps have already been backed upon cloth and properly arranged. The detail of a clerk for this special purpose during the summer is contemplated and it is hoped that on the return of the field parties in the fall they will find the large collection of American maps as accessible as the books upon the shelves.

PUBLICATIONS.

The publications of the Survey have now become so important and so numerous that the force needed for their care and distribution has become of itself a distinct division, and the responsibility imposed thereby upon the librarian claims a very large part of that time which should be given to the library proper. One thoroughly accurate man to whom could be safely delegated the supervision of this force and this work would amply compensate for his salary by the time thus saved to bibliographic work.

The publications now issued are the following:

Annual reports.

First Annual Report to the Hon. Carl Schurz, by Clarence King. 1880. 8°. 79 pp., 1 map. A preliminary report describing plan of organization and publications.

Report of the Director of the United States Geological Survey for 1880-'81, by J. W. Powell. 1882. 8°. lv, 588 pp., 61 pl., 1 map.

Third Annual Report of the United States Geological Survey, 1881-'82, by J. W. Powell. 1883. 8°. xviii, 564 pp., 67 pl. and maps.

Fourth Annual Report of the United States Geological Survey, 1882-'83, by J. W. Powell. 1884. 8°. xii, 473 pp., 85 pl. and maps.

Monographs.

II. Tertiary History of the Grand Cañon District, with atlas, by Clarence E, Dutton, Captain U. S. A. 1882. 4°. 264 pp., 42 pl., and atlas of 26 double sheets folio. Price, $10.12.

III. Geology of the Comstock Lode and the Washoe District, with atlas, by George F. Becker. 1882. 4°. xv, 422 pp., 7 pl., and atlas of 21 sheets folio. Price, $11.00.

IV. Comstock Mining and Miners, by Eliot Lord. 1883. 4°. xiv, 451 pp., 3 pl. Price, $1.50.

V. Copper-bearing Rocks of Lake Superior, by Roland D. Irving. 1883. 4°. xvi, 464 pp., 29 pl. Price, $1.85.

VI. Contributions to the Knowledge of the Older Mesozoic Flora of Virginia, by William M. Fontaine. 1883. 4°. xi, 144 pp., 54 l. 54 pl. Price, $1.05.

VII. Silver-lead Deposits of Eureka, Nevada, by Joseph S. Curtis. 1884. 4°. xiii, 200 pp., 16 pl. Price, $1.20.

VIII. Paleontology of the Eureka District, by Charles D. Walcott. 1884. 4°. xiii, 285 pp., 24 l., 24 pl. Price, $1.10.

Bulletins.

1. On Hypersthene-Andesite and on Triclinic Pyroxene in Augitic Rocks, by Whitman Cross, with a Geological Sketch of Buffalo Peaks, Colorado, by S. F. Emmons. 1883. 8°. 42 pp. 2 pl. Price, 10 cents.

2. Gold and Silver Conversion Tables, giving the coining value of troy ounces of fine metal, etc., by Albert Williams, jr. 1883. 8°. ii, 8 pp. Price, 5 cents.

3. On the Fossil Faunas of the Upper Devonian along the Meridian of 76° 30′, from Tompkins County, New York, to Bradford County, Pennsylvania, by Henry S. Williams. 1884. 8°. 36 pp. Price, 5 cents.

4. On Mesozoic Fossils, by Charles A. White. 1884. 8°. 36 pp., 9 pl. Price, 5 cents.

5. A Dictionary of Altitudes in the United States, compiled by Henry Gannett. 1884. 8°. 325 pp. Price, 20 cents.

6. Elevations in the Dominion of Canada, by J. W. Spencer. 1884. 8°. 43 pp. Price, 5 cents.

7. Mapoteca Geologica Americana. A catalogue of geological maps of America (North and South), 1752-1881, by Jules Marcou and John Belknap Marcou. 1884. 8°. 184 pp. Price, 10 cents.

8. On Secondary Enlargements of Mineral Fragments in Certain Rocks, by R. D. Irving and C. R. Van Hise. 1884. 8°. 56 pp. Price, 10 cents.

9. A Report of work done in the Washington Laboratory during the fiscal year 1883-'84. F. W Clarke, chief chemist; T. M. Chatard, assistant. 1884. 8°. 40 pp. Price, 5 cents.

10. On the Cambrian Faunas of North America. Preliminary studies by Charles D. Walcott. 1884. 8°. 74 pp. 10 pl. Price, 5 cents.

11. On the Quaternary and Recent Mollusca of the Great Basin, with descriptions of new forms, by R. Ellsworth Call. Introduced by a sketch of the Quaternary Lakes of the Great Basin, by G. K. Gilbert. 1884. 8°. 66 pp., 6 pl. Price, 5 cents.

12. A Crystallographic Study of the Thinolite of Lake Lahontan, by Edward S. Dana. 1884. 8°. 34 pp., 3 pl. Price, 5 cents.

13. Boundaries of the United States and of the several States and Territories, by Henry Gannett. 1885. 8°. 135 pp. Price, 10 cents.

Statistical papers.

Mineral Resources of the United States, by Albert Williams, jr. 1883. 8°. xvii, 813 pp. Price, 50 cents.

Exchange.—The increased facilities for storing and handling these publications possessed since the removal to the new quarters in October, 1884, has enabled me more successfully to carry out our widespread system of exchanges with scientific institutions and individuals; and returns from our first distributions of last year have come in in so large measure and verified to such an extent our address list, that I am able to report in this department very satisfactory results.

The Third Annual Report has been distributed throughout the world to the whole exchange list; bulletins 2, 3, 4, 5, and 6, and monographs III, IV, V, and VI, have been sent to all entitled to complete exchange, making in all 7,900 volumes distributed by exchange alone, as stated in detail in the following table:

Third Annual Report	1,025
Bulletin 2	677
Bulletin 3	677
Bulletin 4	677
Bulletin 5	677
Bulletin 6	677
Monograph III	669
Monograph IV	668
Monograph V	667
Monograph VI	676
Mineral Resources	710
Whole number of volumes distributed	7,800

Sale.—The sale of those publications which can be distributed only by exchange or sale has not been large. All who desired to purchase have been supplied, but no efforts are made to increase their number, as the chief labor has been expended in the system of exchanges for the purpose of collecting a much needed library.

Tabulated statement of sales of publications of the United States Geological Survey during the fiscal year 1884–'85.

Title of work.	Price of work.	Third quarter 1884.		Fourth quarter 1884.		First quarter 1885.		Second quarter 1885.		Whole fiscal year.	
		Volumes.	Amount.	Volumes.	Amount.	Volumes.	Amount.	Volumes.	Amount.	Volumes.	Amount.
Monograph II	$10 12	5	$50 60	1	$10 12	....	....	....	....	6	$60 72
Monograph III	11 00	....	....	....	....	2	$22 00	....	....	2	22 00
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Whole number of volumes sold, 834. Whole amount received for publications, $340.32.

Free distribution.—A very large number of the Second Annual, the Third Annual, and the free edition of Mineral Resources, have been distributed gratuitously, so that the supply of these volumes, save for the immediate needs of the Survey, is exhausted.

CORRESPONDENCE.

The correspondence of this division, including all letters from foreign scientific institutions relating to exchanges, all letters which relate to the purchase of books, and all letters which relate in any way to the distribution of publications, has greatly increased. During the fiscal year there have been sent out from the correspondence division 10,251 letters and forms and a like number received. All these have been indexed and filed so as to permit of ready reference.

I am, with respect,

CHAS. C. DARWIN,
Librarian.

Hon. J. W. POWELL,
Director United States Geological Survey, Washington, D. C.

DEPARTMENT OF THE INTERIOR, UNITED STATES GEOLOGICAL SURVEY.

PAPERS ACCOMPANYING THE ANNUAL REPORT

OF THE

DIRECTOR OF THE U. S. GEOLOGICAL SURVEY

FOR THE

FISCAL YEAR ENDING JUNE 30, 1885.

MOUNT TAYLOR AND THE ZUÑI PLATEAU.

BY

CAPT. CLARENCE E. DUTTON,
ORDNANCE CORPS, U. S. A.

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ILLUSTRATIONS.

LETTER OF TRANSMITTAL.

UNITED STATES GEOLOGICAL SURVEY,
Washington, May 15, 1885.

SIR: Herewith I have the honor to transmit an account of the geological features studied by me last summer in the vicinity of Mount Taylor and the Zuñi Plateau in New Mexico.

Very respectfully, sir, your obedient servant,

C. E. DUTTON,
Captain of Ordnance, U. S. A.

HON. J. W. POWELL,
Director United States Geological Survey.

MOUNT TAYLOR AND THE ZUÑI PLATEAU.

By Capt. Clarence E. Dutton,
Ordnance Corps, U. S. A.

CHAPTER I.

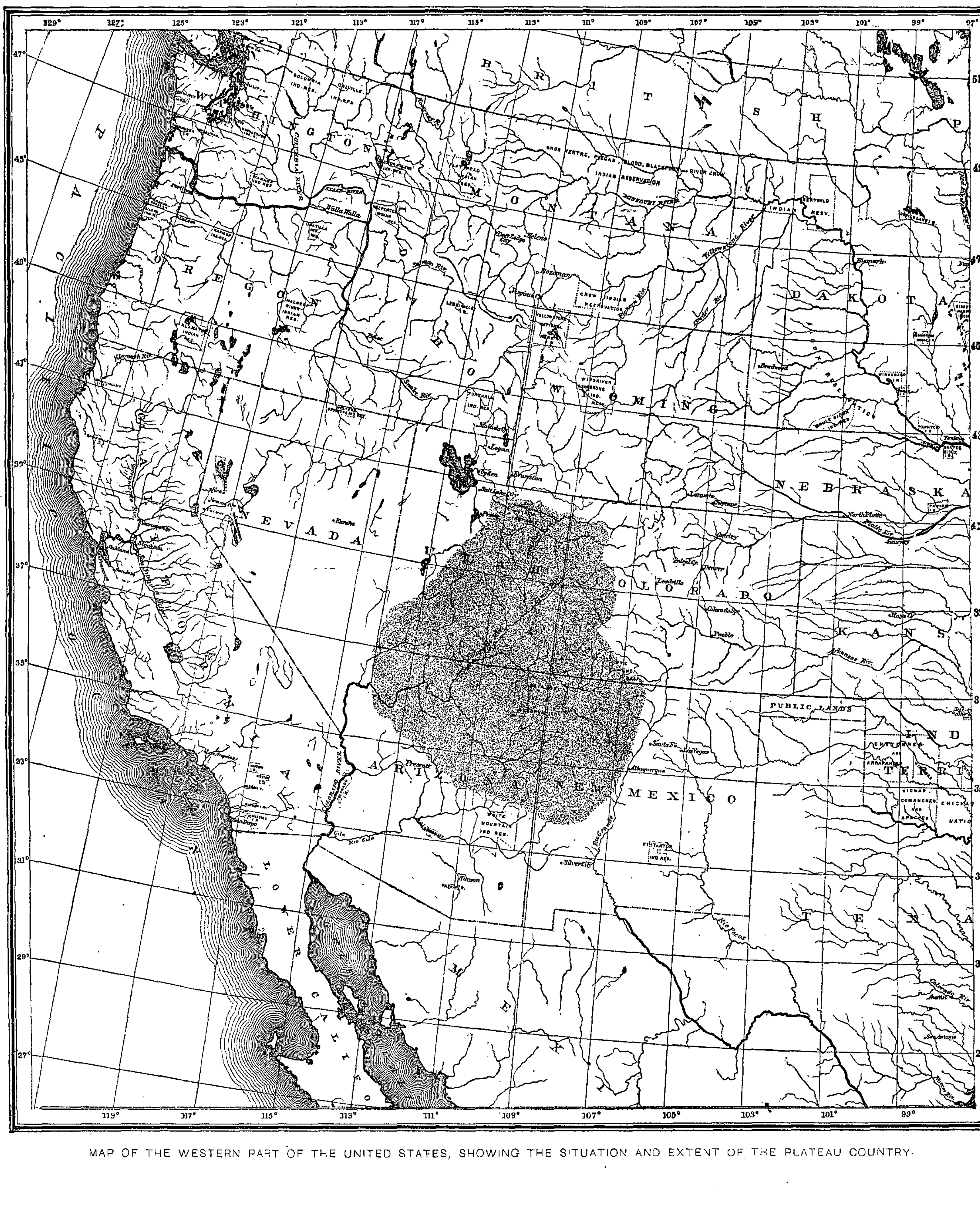
THE PLATEAU COUNTRY AT LARGE.

From 1875 to 1880, both years inclusive, I had been engaged in the study of the western side of the Plateau country. Numerous excursions were made into the heart of this remarkable region both by myself and by those with whom I was intimately associated. Several years before, Powell had studied the Uinta Mountains and the surrounding plateaus, and had made his two memorable voyages down the Green River and the Colorado. Long before that (1857) Newberry had made, with Lieutenant Ives, the famous journey up the Colorado to the western verge of the plateaus, and had traversed from west to east the great tableland which lies to the south of the river; two years later he had made another excursion from Santa Fé to the junction of the Grand and the Green. Gilbert and Howell also had rapidly traversed the northwestern part of New Mexico, passing through the district to be described in this little memoir, and had been engaged in the study of portions of the western side of the province. In 1876 the former visited the Henry Mountains, in the center of the Plateau country, where he obtained results of inestimable value to geological science, with which his name will always be associated. In daily intercourse with Powell and Gilbert, and with a bond of affection and mutual confidence which made the study in a peculiar sense a labor of love, this geological wonderland was the never-ending theme of discussion; all observations and experiences were common stock, and ideas were interchanged, amplified, and developed by mutual criticism and suggestion. The extent of my indebtedness to them I do not know. Neither do they. I only know that it is enormous, and if a full liquidation were demanded it would bring me to bankruptcy.

No geologist possessing any breadth of comprehension could enter such a region and, after gaining an extended knowledge of its physical features, fail to perceive that it is a great unit, a thing distinct in itself, and sharply delimited from everything which surrounds it. So great, however, is its area that the work of many explorers, lasting through years of painful travel, was necessary before the first rough outline and most general conception of its extent could be determined. At the time of my own work in the western part of the province, these first determinations had been approximately reached through the combined results of the studies of Newberry, Powell, and the forces under Hayden and Wheeler. It remained to study in detail the wonderful features of the region and the great problems associated with them. From the lofty crest lines of the High Plateaus, and from the highest points in the Grand Cañon district, my thoughts had often reached out to the eastward beyond the farthest limit of vision, and I longed to see the extensions of those vast masses of strata and the features carved out of them in regions beyond the horizon. Problems which could be only half solved on the western side might be completely solved on the eastern. Many problems turned upon data which could not be local, but which were general for the whole province. Its history and evolution, the chronology and sequence of its most important events, could be ascertained satisfactorily only by knowing the whole. At length an opportunity came.

It had been decided by the Director that I was to take up the study of the great volcanic field in the Cascade Range; but in 1884 the topographic survey and mapping of that country had not sufficiently progressed to enable systematic geological work to proceed satisfactorily. Meantime the topographic parties which had been engaged in mapping Northwestern New Mexico had just brought back accounts of some striking features in the vicinity of Mount Taylor, and these awakened so much interest that the Director was of the opinion that a single season could be spent with advantage in studying them. The Cascade business was therefore postponed for a year, and I was ordered to New Mexico to see what was there. The result of the summer's work is set forth in the following pages. The field is one which embraces types of features characteristic of the Plateau province; and inasmuch as I am desirous of putting it into its natural relation with that province as a whole, I shall preface the account with a summary view of the Plateau country in its entirety, so far as present knowledge will enable me to do so. Indeed such a course seems necessary. In geological descriptions much is lost by the common practice of failing to show how a district or limited tract is related to its environment, and what part it plays in a grand whole. Without such a correlation a description has little interest or ulterior meaning.

A glance at the accompanying map (Plate XI) will show the situation of the Plateau country with reference to the western portion of the United States, so far as now understood. There is some uncertainty about the exact positions of some parts of its boundary arising from two causes. In the first place, while some portions of this region are



MAP OF THE WESTERN PART OF THE UNITED STATES, SHOWING THE SITUATION AND EXTENT OF THE PLATEAU COUNTRY.

sharply defined and their limits are clear enough to the most superficial observation, there are other portions where there is not, so far as we now know, any sharp boundary, but rather a gradual transition separating it from adjoining regions. Secondly, those portions of the boundary which are least definite happen to be the ones which have been the least studied. There are two distinct regions possessing the Plateau types of topography and structure—a northern and a southern. They are separated by the Uinta Range of mountains. With the northern division, drained by the upper branches and courses of the Green River, we shall have nothing to do. Though similar, and even homologous, in most respects to the southern country, it is less pronounced, less impressive and wonderful, perhaps less typical. The main features and the grander subjects are found in the southern division. For us the Plateau country shall mean that division which lies south of the Uintas.

The northern boundary of the southern Plateau province is sharply defined at the base of the Uinta Mountains, where the platform of the country is suddenly upturned to form the southern slope of that great range, and the lower and older rocks are protruded upwards. It will be remembered that the Uintas are an exception among the mountains of the West, for their trend is due east and west, while the other ranges stretch more or less nearly north and south. This range joins the Wasatch (to the west) at a right angle, and the latter then becomes the boundary of the plateaus. The limit is still sharp and distinct and of the same general character as at the base of the Uintas, except that its course is now north and south instead of east and west. A little more than a hundred miles south of the junction of the two mountain chains the Wasatch dies out, and the plateaus lap around its southern end. But the boundary still maintains its trenchant character. The high plateaus of Central and Southern Utah now constitute the border of the province, and at their western margins the topography and structure pass at once into the strongly contrasted features of the Great Basin. Beyond the southern end of the Wasatch and as far as the southwestern corner of Utah the course of the boundary line is southwestward. Then it turns due south again. The High Plateaus end in Southern Utah and cease to be the western border of the province. They are succeeded southward by the great platform of the Grand Cañon district. This platform north of the Colorado River ends westwardly in a giant wall overlooking the same jagged, wild topography that we find in the Great Basin, and which is continued far to the south and into the western part of Arizona. Crossing the Colorado River the plateau boundary slowly swings more and more to the eastward. The Grand Cañon platform is still the border ground, suddenly ending in a great cliff overlooking southwestwardly the prolongation of the Basin type of topography. Through a stretch of more than 400 miles this same mode of demarkation continues between the abruptly ending plateaus on the northeast and the contorted, bristling, craggy mountain ranges on the southwest. The Basin type of structure extends far beyond the literal Great Basin as defined by Frémont. It stretches from the Columbia River—perhaps from a much higher latitude—uninterruptedly to the Colorado, and then swings around the plateau margins southeastward to the Rio Grande Valley.

The Plateau country attains its greatest southing in the southwestern part of New Mexico. Little is known of its geology there. Its boundary then swings around to the northeast and finally to the north, where it touches the Rio Grande River. The river now becomes for a time the definite and unmistakable bounding line. At length, some twenty miles north of Albuquerque, that remarkable sharpness of limit which thus far has characterized its edges is no longer seen, and its separation from the region which embraces the Rocky ranges of Colorado and of Northern New Mexico is more or less arbitrary.

But before attempting to follow it out let us look once more to the southernmost promontory of the plateaus. Whoever has examined, even cursorily, the map of Western America must have noticed the following arrangement of the mountain masses: The great belt of cordilleras coming up through Mexico and crossing into United States territory is depicted as being composed of many short, abrupt ranges or ridges, looking upon the map like an army of caterpillars crawling northward. At length, about 150 miles north of the Mexican boundary, this army divides into two columns, one marching northwest, the other north-northeast. The former branch becomes the system of mountain ridges spread over the southern and western portions of Arizona, the whole of Nevada, and the western portion of Utah, and extending into Oregon and Idaho. Wherever these ranges have been examined geologically they exhibit the Basin type of structure. They are masses of older strata, often metamorphic and granitic, tilted up at considerable angles, always more or less faulted, and considerably warped and flexed. Erosion has given them a singularly rough, jagged, angular aspect, and has left them no trace of symmetry or regular form. The other branch, which leads north-northeastward from the fork, is narrower, and has very few and widely scattered ranges. Near the fork they have some similarity to the Basin types, but gradually acquire, as we proceed northward, a structure of their own. At length their northward continuation develops into the great front and middle ranges of Colorado—the Alpine masses to which custom has finally restricted the old name of Rocky Mountains. This split in the main chain of cordilleras, forming the Basin ranges on the west and the Rockies on the east, leaves between them the vast area of the Plateau country. I have already shown how trenchant is the boundary which divides the plateaus from the region of the Basin ranges both in Arizona and in Utah. This definiteness of limit is maintained to the very fork where the two mountain systems separate, and right in this fork is the southernmost promontory of the Plateau country. But the eastern boundaries of the plateaus are not so clear in all cases, though in some parts there is no reason to hesitate. For a distance of 200 miles the Rio Grande may be taken as marking the boundary; and though it may not be exactly coincident throughout this entire space, it is so throughout much of it and is never far from it. Near the boundary line between New Mexico and Colorado, in the valley of the Rio Grande, we come upon the southern terminations of the Sangre de Cristo and San Juan Ranges. These are mountain platforms of the Rocky system, and the plateau boundary follows along their western bases. Crossing the State line it enters Colorado, first with a general northwesterly, afterward a northerly, trend, keeping always close to the western bases of the Rocky ranges until it reaches the place of beginning, at the eastern end of the Uintas. The area of the Plateau country thus described may be stated approximately at 130,000 square miles.

It will be impossible here to do more than pass in hurried review the principal features of the Plateau country. The name might seem to imply a smooth and level region, but it is one of the ruggedest portions of the West. The topographic obstacles to travel are even greater than in the wilder parts of Colorado; but instead of mountains with sloping flanks we find innumerable cliffs, often of great altitude and length, stretching across our pathway or vanishing on either hand into the dim distance. The main drainage channel is the Colorado River. For many leagues on either side of it the country is cut by numberless tributary cañons, such as are never seen elsewhere. They are many hundreds of feet in depth, scores of miles in length, and their walls are precipitous in the extreme.

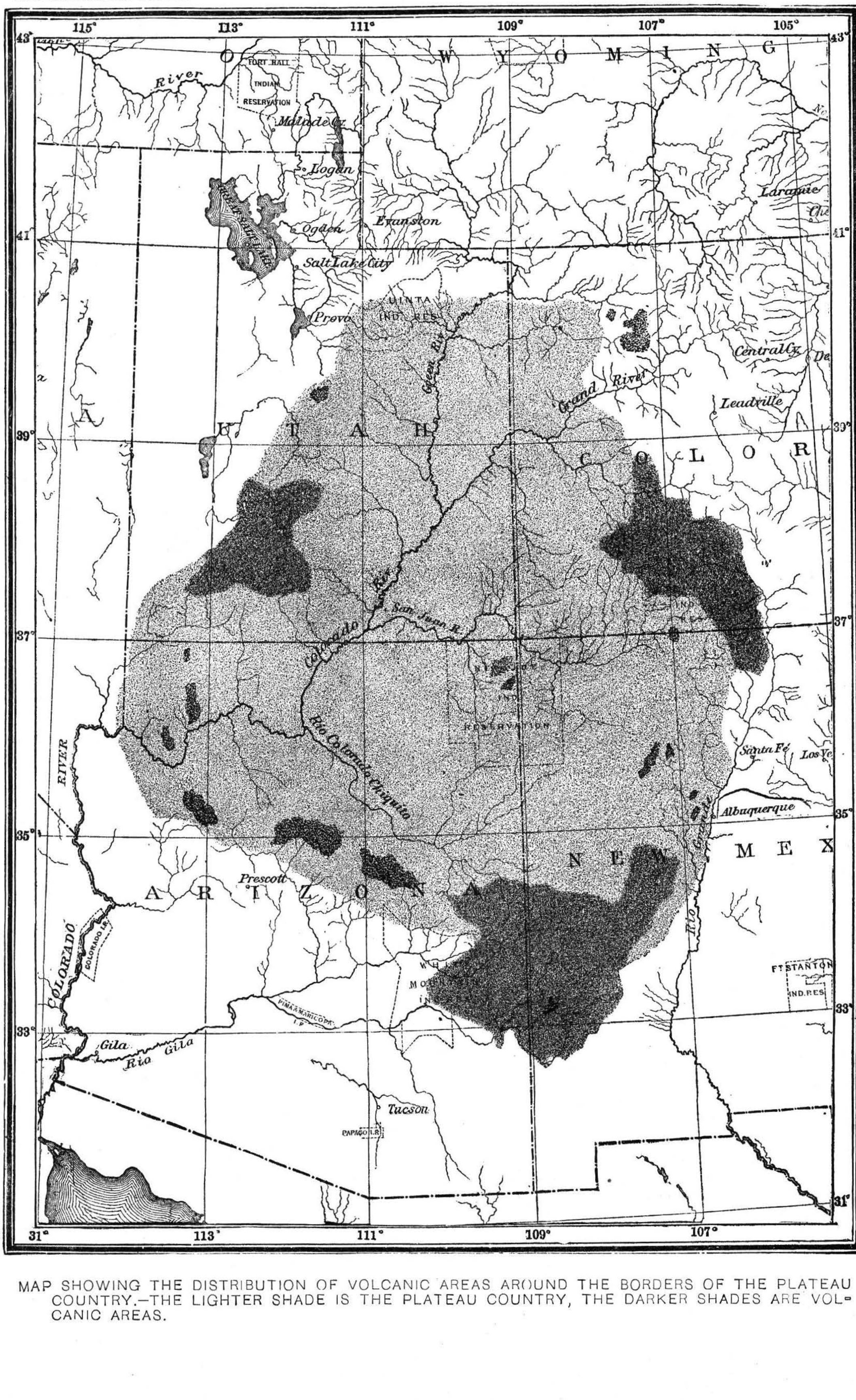
The surfaces of the innumerable platforms into which the country is subdivided are usually rather smooth or moderately undulated, either level or slightly tilted. Few of them are of any great extent, and they generally terminate at the brink of some gigantic wall, which drops the profile almost vertically upon some lower level until the lowest is reached. The most extensive unbroken platforms are those in the vicinity of the Grand Cañon. The altitudes of these platforms vary greatly. Some are as low as 4,000 feet above the sea, others as high as 10,000 to 12,000 feet. The average altitude may be stated rather roughly at 6,500 feet.

The topographic features and extraordinary scenery of this region have been described many times, and it may be needless to descant upon them. From the standpoint of the geologist, however, it is desirable to advert to those stratigraphic and structural features to which this topography and scenery stand in the relation of effects to causes. Except as hereafter described, the strata lie in a nearly horizontal position. The inclinations, which are frequent enough, are at so slight an angle that the impression upon the observer is much the same as that produced by strictly horizontal bedding. There is also a remarkable uniformity and persistence of character in the component materials of the respective formations and in their mechanical arrangement. We can trace single beds or restricted groups of beds for many leagues without observing any appreciable lithologic changes in them or any notable variation in color and thickness. But while the inclinations or dips of the strata are very slight and their thickness is but little variable, we find that such dips as do occur are often maintained through great distances without any recurvature of the beds. These persistent dips, therefore, carry the strata from very high altitudes to very low ones. Ordinarily, when these protracted dips occur, the formation which is exposed at the summit of the incline is lost to view after a few miles by the occurrence of some later and higher formation, which thereafter overlies and buries it. This second formation takes the same dip as the first, and after a few miles is lost to view in its turn by the advent of a still higher one. Each formation thus appears as a terrace, bounded on one side by a descending cliff carved out of the edges of its own strata, and bounded on the other by an ascending cliff carved out of the strata beyond, which overlie it. These terraces are very numerous all over the Plateau country, and are highly characteristic. In the course of this little memoir we shall perhaps learn something of their origin and mode of development.

Another characteristic group of geological features is found in the displacements or dislocations of the strata. In other countries exhibiting considerable disturbance of the strata, we find the beds undulated, with anticlinal crests and synclinal troughs succeeding each other at brief intervals. There are many flexures of the strata in the Plateau country, and gigantic ones, too; but I do not know of a single well-marked typical anticline or syncline in all its broad expanse. The flexures are invariably monoclines.

The term "monocline," in the sense in which it is here employed, is a comparatively new one in geological nomenclature, and was first used to designate the flexures of the Plateau country. Such displacements had rarely been observed in other regions, though of late years the conspicuous examples brought to light in Utah and Arizona have led to their recognition in other localities, where their configuration had previously been obscure. Many of these monoclines are of great length and of great displacement. A length of sixty to eighty miles is common, and still longer ones are known. The displacement is sometimes as great as 3,000 feet, *i. e.*, the strata ascend along its slope by that amount. The inclination of the beds on the slope of the monocline is very variable, ranging from a few degrees from the horizontal to nearly vertical.

Besides the monoclinal displacements, we also meet with great faults, where the strata are neatly sheared and hoisted on one side or depressed on the other. These faults, also, are remarkable for their great length and for the amount of displacement, often exceeding in these respects the monoclines. Indeed, the two forms of displacement are not always wholly distinct, for the monoclinal dislocation frequently passes grad-



MAP SHOWING THE DISTRIBUTION OF VOLCANIC AREAS AROUND THE BORDERS OF THE PLATEAU COUNTRY.—THE LIGHTER SHADE IS THE PLATEAU COUNTRY, THE DARKER SHADES ARE VOLCANIC AREAS.

ually into a fault, and *vice versa*. Some of these grand structural features I have described in former works, and others will be spoken of in the subsequent pages.

The Plateau country also abounds in volcanic rocks and extinct volcanoes. It is observable at once that the eruptions have occurred chiefly around the borders of the province, while the interior spaces disclose only occasional traces of them. The ages of these eruptions vary greatly. Some are as old, probably, as Middle Eocene time; others are so recent that it seems almost certain that they occurred within the last thousand years, and there is no intrinsic improbability that some of the earliest Spanish visitors may have witnessed them, though they have left us no records. In the intervening periods many eruptions occurred at one place or another, and no long period of time seems to have elapsed without them.

The distribution of the volcanic masses is of some interest, for we may perceive how they are associated with the marginal portions of the province and occur very sparingly in the interior parts of it. Near the southern base of the Uintas we do not know of any large or important masses of volcanic rocks. But our knowledge of that portion is not sufficient as yet, and future examination may disclose much more eruptive material than we are now aware of. Some scattered occurrences, however, are known there. Upon the eastern flank of the Wasatch there are many patches of old lavas, but none of very great dimensions are known. South of the Wasatch, in the district of the High Plateaus of Utah, we come upon enormous masses of volcanic rocks, covering an area of nearly 9,000 square miles, and attaining in many portions a thickness of three to four thousand feet. Most of these are of great antiquity, going back to Middle Tertiary time, and some of the oldest ones, perhaps, to Eocene time. But there are others which are far more recent, and it seems extremely probable that the latest of them have been erupted within a few hundred years. Southwest and south of the High Plateaus are many minor volcanoes, now wholly extinct; and as we descend to the Grand Cañon platform we find cinder-cones, most of them well preserved, scattered about among the cliffs and terraces. As we approach the great chasm along its western half we enter several extensive volcanic fields, in which cinder-cones are thickly clustered. Many streams of basalt have flowed from them, flooding many hundred square miles of desert. Cones and lavas both show that no great length of time has passed since they were in action.

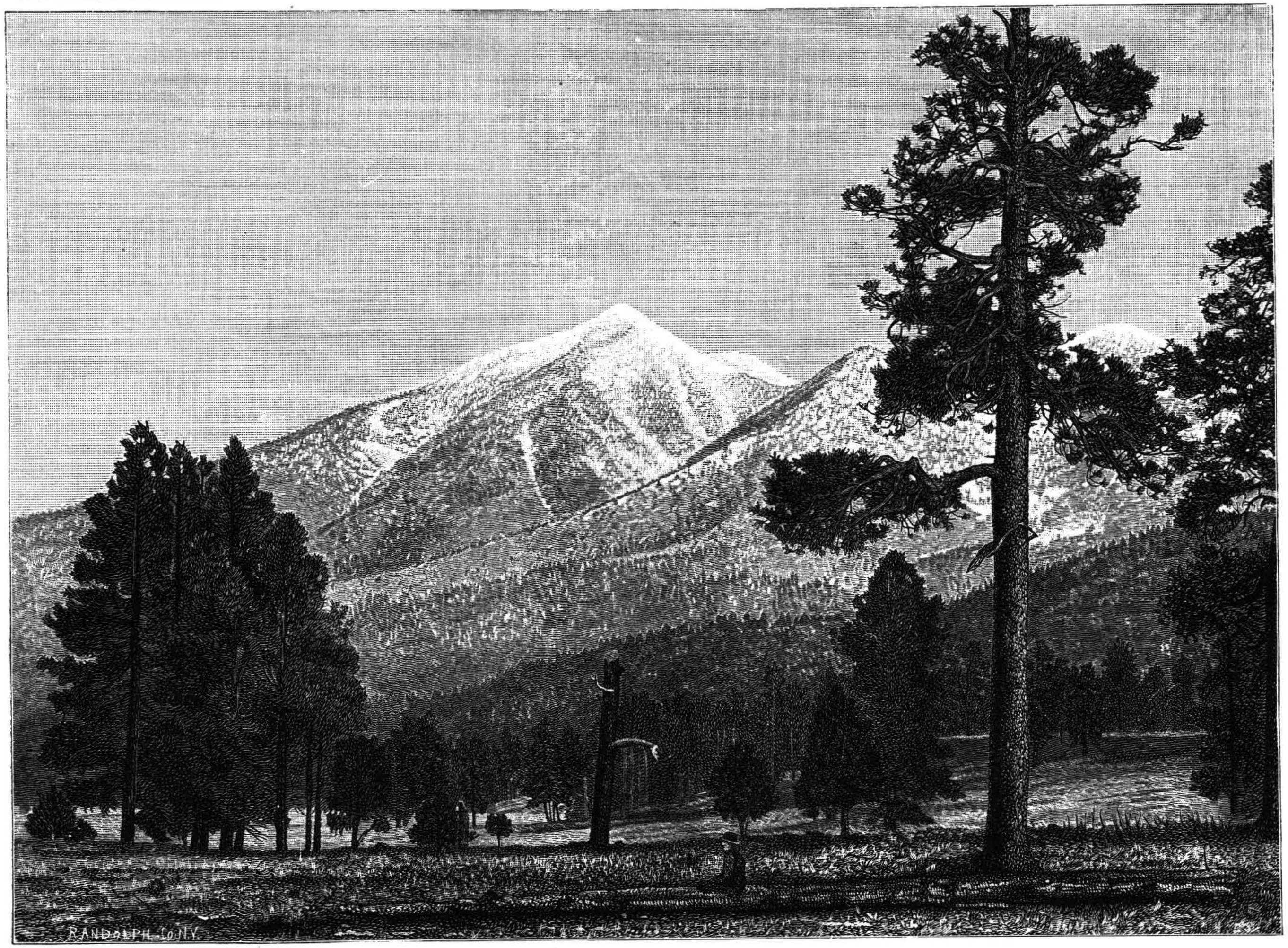
Crossing the Grand Cañon, and still near the margin of the Plateau country, we find the respectable volcanic pile of Mount Floyd, and a little farther on we reach the much grander masses of the San Francisco Mountains. Here is another large volcanic district, though much inferior to the High Plateaus both in the area and in the thickness of the lava sheets. But it possesses what the High Plateaus do not, viz, great volcanic mountains. The principal pile, San Francisco Mountain, is a cone of almost the first order of magnitude. Its altitude above the sea, according to Wheeler, is 12,562 feet, and it is the loftiest peak in the southwestern part of the country. It has long been extinct and is greatly battered by erosion.

Proceeding southeastward, and still keeping near the margin of the plateaus, we have hardly left the lava fields which center around these great volcanoes when we enter upon much more expansive ones. On all the old maps of Arizona we see roughly delineated the so-called "Mogollon Mountains." They are merely the lofty crest of the plateaus looking down southwestward over the Sierra country. This crest and the table-land north and east of it are thickly sheeted over with lavas, and the area so covered is to be reckoned only by thousands of square miles. It has not been studied as yet by the geologist, and our knowledge of it is too imperfect to justify the attempt to describe it. Still further to the southeast, as far as the southernmost promontory of the Plateau country, the volcanic fields increase until they reach their maximum expanse. But they have never been studied.

Passing out of this great lava field and coming northward along the eastern margin of the plateaus in the Rio Grande Valley, we find many isolated patches sheeted over with lava. Indeed, we are seldom out of sight of them. Some are of considerable extent, others are hardly more than individual *coulées*. West of Albuquerque we find the lava fields very abundant, and in the vicinity of the San Mateo Mountains they become very extensive and present features of the greatest interest and some novelty. This particular locality is to be one of the principal themes of the following chapters, and its discussion will be passed over for the present.

The remaining portion of the Plateau boundary has already been characterized as rather indefinite (perhaps from want of accurate knowledge), but it still exhibits abundant relics of volcanic action. The San Juan Range is almost wholly buried in lavas and volcanic conglomerates. But this range has been regarded as lying just without the margin, instead of within it. Still we find traces of old eruptions within the border, in the shape of dikes and necks, which are left projecting above the surface, often to considerable altitudes, showing that the lavas have once been there, but that they and some of the sedimentary strata which they covered have been swept away by erosion and have vanished forever from view.

Thus the fact is general that around the borders of the Plateau country volcanic eruptions have been frequent. In making its circuit we are seldom out of sight of them, and if the journey were actually performed by a geologist he could so conduct his route that for three-fourths of the way he would be treading upon eruptive materials and pitch his camp upon them every night. So far as we now know none of these eruptions are older than Tertiary time; but within that limit they are of



SAN FRANCISCO PEAK.

many ages, and some of them are extremely recent. In the heart of the Plateau country volcanic rocks are scarce. Still they occur, but under circumstances which are always interesting and suggestive. It is no uncommon thing in the heart of the Plateau region to come suddenly upon a long, narrow wall of black rock projecting hundreds of feet in air, rising out of a flat plain. The rock is a dike of basalt or andesite; but the dike itself is all the eruptive material we see — no lava stream overflowing the adjoining plain, no cinder-cone, no bed of volcanic rubbish. A critical examination of the rock indicates that it has consolidated under pressure. Instead of long, narrow dikes we often find sharp pinnacles, towers, and spires of the same black rock rising 1,000 feet or more. The people who herd cattle in the vicinity call them needles. The geologist would call them "necks." They are the lavas which consolidated in the pipes or orifices in the strata through which they came up, while the strata themselves have been swept away, leaving these cones standing. The rock of which they are composed is more enduring against the battering of time than the sandstones and shales which once held them. It appears, then, that the scarcity of lavas in the interior spaces of the Plateau country is no measure of the actual quantity of extravasation which has occurred. Lavas have been outpoured there, but have been swept away in the general wreck of the land, leaving only these stumps of volcanoes to tell the tale. How extensive these eruptions may have been we cannot judge with accuracy. Still we are not without the means of inferring with considerable confidence that they were never comparable to the vast masses now visible around the borders of the province.

Another singular mode in which eruptive rocks occur was first shown by Mr. G. K. Gilbert, in his admirable work on the Henry Mountains. There the lavas, instead of reaching the surface and outflowing in broad streams, intruded themselves between the strata in great lens-shaped masses half a mile or more in diameter and several hundred feet thick. The beds above them were domed up, and are now seen curving over them. To these intrusive masses, Mr. Gilbert gave the name "laccolites." They present many points of interest, which he has ably discussed. There are several isolated groups of mountains within the plateaus which exhibit this peculiar action, such as the Sierras Carriso, Abajo, La Sal, La Plata, and El Late.

There is another group of geological occurrences in the Plateau country which is full of instruction. No special name has yet been applied to them, though in a single case a name has been given, and this case is quite typical. It occurs in the heart of the Plateau region, northeast of the High Plateaus, and is called the San Rafael Swell. A description of it will be found in the Second Annual Report of the United States Geological Survey (1881–'82), page 56. Although the name "swell" is very unsatisfactory, we will adopt it for awhile in the hope of finding a better one.[1] There is a considerable number of these in the plateaus, and they are of great importance by reason of their association with the most impressive features of the region. They are the localities of maximum erosion. They are the centers from which the dissolution of the strata, through the wasting of their edges, has proceeded outwards, in ever-expanding circles, one bed or formation following another, until thousands of feet in thickness and thousands of square miles in area have been swept away. Along with this denudation has occurred a doming up of the strata into a broad, gently swelling boss. The details of this process and its significance will be discussed in a future chapter; for one of the finest examples of it is found in the Zuñi Mountains, which are, in fact, a perfect homologue of the San Rafael Swell.

The district which it was my privilege to study during the summer of 1884 lies in the southeastern part of the Plateau province. In these parts the Rio Grande River forms a well marked and decisive boundary of the Plateau country. The eastern margin of the district examined lies about fifty miles west of the river. It is a tract embracing two degrees of longitude and one degree of latitude. To explain why such arbitrary limits to the field of exploration were chosen, it may be stated, that when the Geological Survey prepares its maps the unit area chosen for the general atlas sheets is that contained within two degrees of longitude and one degree of latitude. A geologist needs a map as the basis of his work, and as this sheet was just completed, it was adopted as the field of study. Within the area thus mapped (between longitude 107° and 109° and latitude 35° and 36°) occur two distinct categories of geological phenomena; one an exceptionally interesting exhibition of volcanism, the other a fine instance of those peculiar elevations of which the San Rafael Swell is the type. Both are full of instruction and they will be discussed separately.

The volcanic field which I shall describe centers around Mount Taylor, a large solitary volcanic pile situated about sixty miles west of the Rio Grande River. It has for some years been regarded with special interest alike by geographers and by geologists. The other field which immediately adjoins it is the Zuñi Plateau; or as it is designated on the maps, Zuñi Mountains. It has always been my desire to discuss only such geological fields as present a series of facts which can be g ouped together into a definite, easily comprehensible whole, and to avoid a subject which has, so to speak, neither head nor tail to it. Both of these fields have form, consistency, and unity. They are individualized features and each teaches us a lesson worth learning.

Soon after the cession of this region to the United States, at the close of the Mexican war, it was traversed by numerous Government expe-

[1] How this name got into the nomenclature of Western topography, I do not know. I found it there the first time I visited the country. It seems to be quite local and attaches only to the San Rafael district. I am extremely averse to coining names, and have taken up this one rather than invent a new one.

ditions, generally under the command of officers of the Topographical Engineers. The objects of these expeditions were many, but all of them looked to the acquisition of information for military purposes, and above all, for the location of the best routes of communication by land across the continent and of intercommunication between the scattered military posts. Whatever other information could be readily attained without inconvenience to the primary objects was eagerly gathered, and the amount of it was considerable. One of the routes embraced in the grand scheme of explorations for a route suitable for a Pacific railway in 1853, lay through this country. It was commanded by Lieut. A. W. Whipple, who was accompanied by Mr. Jules Marcou as geologist. Mr. Marcou proved himself to be a diligent investigator, and brought back a considerable amount of valuable information, some of which relates to the very locality which is to be discussed in this paper. He has embodied it in his work Geology of North America.[1]

The want of a good topographic map prevented the greater degree of accuracy which Mr. Marcou would otherwise have given to his delineations, but the material for making one did not then exist. He has shown much skill and acumen, and the modifications which fuller and more detailed information, with much better maps, requires us to make in his conclusions are not radical.

In the year 1857 the memorable journey of Lieutenant Ives was performed, and Dr. J. S. Newberry accompanied this expedition as geologist. To Dr. Newberry we owe the first intelligible account, not only of the great chasm of the Colorado, but of the broader geological and topographical features of the plateaus which lie to the south and southeast of the river. Lieutenant Ives ascended the Colorado River for a distance of more than 400 miles from its mouth in a light-draught steamboat; and when he could sail it no further he left it, with his party. Striking southeastward he at length ascended the Grand Cañon platform south of the river, and after reaching the bottom of the great chasm at Diamond Creek, and nearly reaching it in Cataract Cañon, he turned southeastward to the San Francisco Mountains. Thence he proceeded to the Moki towns and Fort Defiance. From the latter post Dr. Newberry went homewards through the district which is to be specially discussed in the following pages. His route touched the course now followed by the railroad, at Mineral Spring, which lies between Wingate Station and Gallup, and continued thereafter along the present line of the railway to the eastern limit of the map, near Laguna. It was during this long journey that Dr. Newberry recognized the grand geological fact which is dominant over all others in the Plateau country — the immensity of the work which erosion has there accomplished. To recognize that the cañons are the work of erosion does not require

[1] Geology of North America, by Jules Marcou, Zurich, 1858. Printed for the author by Zurcher and Furrer. In that work the Zuñi Plateau is called the Sierra Madre Mountains. This latter name is preoccupied.

that the observer who has seen them should be a geologist or much of a philosopher; but to see, as Dr. Newberry did, from such hasty views of so small a portion of this great province, that the cañons are merely the last finishing touches of an erosion incomparably more vast, required no ordinary penetration. The stratigraphic work which he accomplished will probably never require much emendation, though in details it may be amplified. It is the work of a master. Whatever theme he touches upon is handled with thorough learning, and what is better still, with sagacity. It is a matter of surprise and envy to the younger geologists who have followed in his footsteps to see how much of real value and importance he found to say with his very imperfect opportunities, and how little he will have to retract or defend.

In the year 1873 Lieut. (now Capt.) G. M. Wheeler's parties traversed this country, with Mr. G. K. Gilbert and Mr. Edwin E. Howell as geologists. The results of their observations are published in Volume III, Geology, of the Reports of the Survey West of the One Hundredth Meridian. Their accounts are very meager and could not have been otherwise, for they were mere accessories of rapidly moving parties engaged in a topographic reconnaissance. Under such circumstances connected geological work is quite impossible. Still their notes are of real value and were found to be highly suggestive. In connection also with the surveys of Captain Wheeler, the distinguished paleontologist, Prof. E. D. Cope, visited New Mexico and made many interesting discoveries.

His notes upon the stratigraphy of the country in the vicinity of Santa Fé are very valuable. The survey of Dr. Hayden did not extend farther into New Mexico than a few miles south of the Colorado boundary. But a portion of the Plateau province is included in the southwestern part of that State, and the geological features there presented are in most respects so clearly identical with those farther south that the closest correlations can be made. Mr. W. H. Holmes's work in the valley of the San Juan River becomes therefore of great importance in this connection, and the more it is studied the more evident it becomes that Mr. Holmes is as accomplished in field work as he is with his pencil. (Hayden's Annual Report for 1876.)

Thus the region under discussion is by no means a new field geologically. Able geologists have visited it before and have pointed out many of its salient facts. But the geological work done there has necessarily been of the fragmentary, running-reconnaissance kind, which scarcely admitted of generalization. Neither the knowledge of the essential facts of the region itself nor that of those which adjoin it nor of the great province of which it is but a small part, was sufficient to justify the attempt to give a comprehensive view of it either as a unit in itself or as a part of a great whole.

CHAPTER II.

THE GENERAL FEATURES OF THE DISTRICT.

At the town of Albuquerque in New Mexico, and for a distance of many miles north and south of it, the Rio Grande may for the present be regarded as forming the boundary of the southeastern part of the Plateau country. A few miles east of the town rises the Zandia Range, a large and rather imposing mountain ridge, which reminds us in every feature of some of the characteristic ranges of the Great Basin, perhaps of the Southern Wasatch at Provo. The Zandia Range belongs to that branch of the Cordilleras which trends from the Mexican boundary a little east of north, and eventually expands into the great Rocky Ranges of Colorado. Looking westward across the Rio Grande a new topography begins, the topography of the Plateau country. From the house-tops of the town we recognize it at once; and if we take the cars of the Atlantic and Pacific Railroad, which here leaves the Atchison Topeka and Sánta Fé, we shall soon find ourselves within it. Ten miles south of Albuquerque the railroad crosses the river and at once winds its way into the land of cliffs, terraces, and cañons. For more than 120 miles the track steadily ascends with a strong gradient until it reaches the Continental divide, which separates the waters which flow into the Gulf of Mexico from those which run to the Gulf of California. The condition and aspect of the country along this route need little description, for many travelers have described it already. The lowlands near the river are barren and desert in the extreme. The highlands are moderately moist and well timbered.

In the immediate valley of the Rio Grande the climate is temperate in winter and insufferable in summer; higher up the summers are temperate and the winters barely sufferable. Below, vegetation is limited to scanty grass during a part of the year and such growths as irrigation can be made to produce. Natural trees on their native heaths are limited to the cottonwoods and willows in the river bottoms. Even the sage-brush, the ashy bloom of the desert elsewhere, resents the scorching summer and refuses to stay, and the cacti, vengeful and repellant everywhere, here assume a still more cruel and misanthropic mien. Higher up the junipers begin to appear, at first gnarled, stunted and timid, at length bold, exuberant, and well favored. Still higher the yellow pines become abundant and cover thousands of square miles of mesa and upland with magnificent forests.

A few miles west of the river we observe around us the low ledges of eroded strata lying nearly horizontal, the beginnings of those cliff and terrace forms which grow higher and grander as we advance. The rocks round about are of Cretaceous age, belonging mostly to the lower members of that great series. Here and there erosion has cut through them, disclosing patches of the beds belonging to the upper portion of the Jura-Trias. Traces of volcanic action, too, are abundant. Thin sheets of basalt are seen covering limited areas. Sometimes it mantles the soil of a valley bottom, sometimes it is the cap-sheet of some mesa. It is scattered about in an irregular way, as if the molten stuff had been dashed over the country from some titanic bucket, and it lies like a great inky slop over the brightly colored soils and clays. There is often no trace of a vent or cinder cone marking the spot whence it issued from the earth, and until we reach Mount Taylor we find nothing to remind us of our old conventional ideas of a volcanic mountain. Sometimes, however, the vent is seen, or rather a small cone built up around the vent. A cluster of three or four of them may be seen from Albuquerque as we look across the river, and thin lava streams are readily distinguishable at a distance as they descend to the high bank above the water and are cut off by the wasting of the rocky ledge.

Fifty miles west of the Rio Grande, the railroad leads among more pronounced cliffs and mesas. Further north these cliff bound mesas lie nearer the river; but I have never been over the interval there, and can only speak of it from the impressions received from a distant view. It is much the same as along the vicinity of the railroad. So, too, is it as far as the eye can reach to the southward. Where we first encounter these cliffs they are of no great altitude, but in an inferior way they suggest more impressive ones beyond. Many of the tables have lava caps, but more have none. There are lavas, too, in the valleys and passageways between the mesas, and these valley lavas are seen at once to be much younger than those on the tops of the tables. And by the way, what is a mesa? What is the special significance of this term? And why is it used instead of good Anglo-Saxon? I will answer these questions by asking another. Did it ever occur to the reader how poverty stricken the (I will not say English exactly, but) Anglo-American language is in sharp, crisp, definite topographic terms? English writers seem to have gathered up a moderate number of them, but they got most of them from Scotland within the past thirty or forty years. They are not a part of our legitimate inheritance from the mother country. In truth, we have in this country some three or four words which are available for duty in expressing several scores of topographic characteristics. Anything that is hollow we call a valley, and anything that stands up above the surrounding land we call a hill or mountain. But the Spanish—or Mexican, if you prefer—is rich in topographic terms which are delightfully expressive and definite. There is scarcely a feature of the land which repeats itself with similar characteristics that has not a pat name. And these terms are euphonious as well as precise: they designate things objective as happily and concisely as the Saxon designates things subjective. Therefore we use them. There are no others adapted to the purpose. A *mesa* means primarily a table. Topographically it is applied to a broad, flat surface of high land, bounded by a cliff, the crest of which looks steeply down upon the country below. And the Plateau country is mesa, mesa everywhere—nothing but mesa. It is not at all necessary that the high tabular surface should be completely encircled, or irregularly but completely environed, by a descending cliff. One side may be cliff-bound, while the other dies away by a gentle, barely perceptible declivity into distant lowlands. Still it is a mesa. Or a few miles back of its crest line a second cliff may spring up to a higher flat beyond. Even so it is to the Mexican a mesa, though we might in this case call it a terrace. The Mexican sees but one side at a time, and if that answers to the general conception it is enough for him.

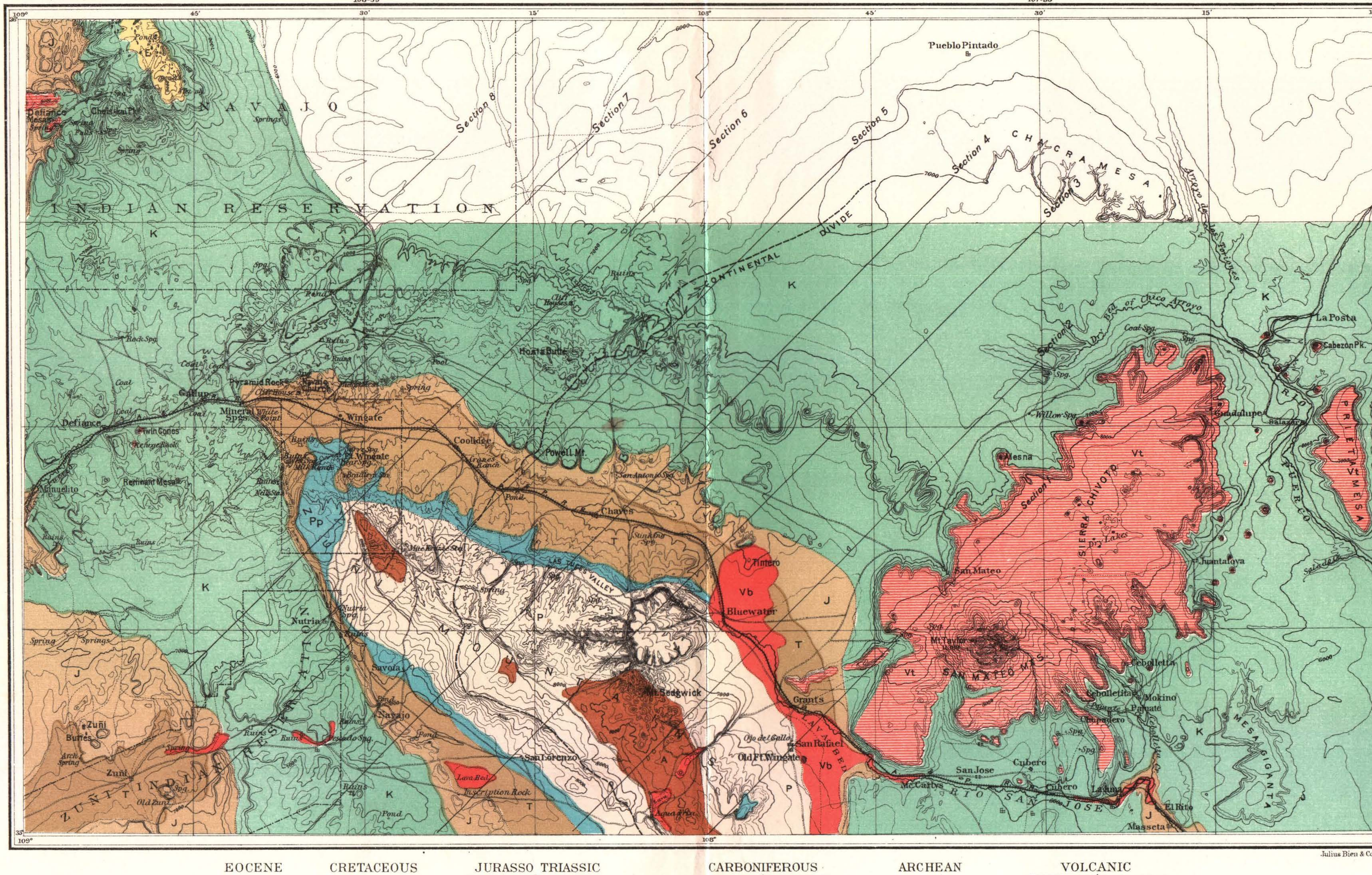
All the various forms of mesas are common in the Plateau country, though the terrace form is perhaps more frequent than the others. While the number of mesas completely engirdled by terminal cliffs is absolutely great, yet relatively it is not so. They are among the less common forms. The courses of their margins are by no means regular. The cliffs sometimes maintain an average trend through vast distances, but in detail their courses are extremely crooked; for they wind in and out, forming alternate alcoves and promontories in the wall, and these in great numbers. Frequently the mesa is breached entirely through by a valley, and this valley may be either a narrow cañon or an interspace ten, fifteen, even twenty miles wide, or any intermediate width.

Where the railroad enters the mesas it finds a breach of this kind cut completely through a long and wide chain of them. It is the valley of the San José. On the north rises the rather imposing pile of Mount Taylor, an old volcano, not of the first and barely of the second order of magnitude. It stands upon a very large mesa of Cretaceous strata everywhere heavily capped with ancient lavas, some of which came from the great central pile and some from the parasitic cones which surround it. On the south is another series of mesas, also of great dimensions, over twenty miles in width, and perhaps fifty miles in length. The highest of these are also heavily lava capped, but no great volcanic pile is supported by them. A few little knobs, barely perceptible at any great distance, prove on nearer view to be the degraded remnants of old cinder-cones, from which much of the lava emanated.

A farther distance of 25 miles carries us through the belt of high mesas. As we emerge upon the western side we find ourselves in a country which is more attractive than that we have left, and with some very picturesque features. At Grant Station (see map, Plate XIV) Mount Taylor bears northeast, while the western fronts of the mesas to the south of it are seen to have somewhat imposing proportions. To the westward rises by moderate slopes a large and rather lofty mass, designated on the map "Zuñi Mountains," though it seems to me more proper to call it a plateau. From every direction, so far as visible, the strata can be seen rising by well marked though never steep slopes to its summit. We shall see much of this great plateau in the subsequent pages. To the northwestward stretches away a broad noble valley. On the right-hand (northeast) side of it we see in the distance a range of highly colored cliffs, loftier than any hitherto encountered. On the left side of the valley are the rather gentle though sufficiently marked slopes of the Zuñi Plateau, clothed all the way up with pines and junipers. In the immediate foreground, and indeed, under our feet and spreading over all the lowlands and plains in front, is a chaos of black, rough lava of peculiarly horrid aspect. Its freshness betokens great recency of eruption; and indeed a very few hundred years only can possibly have passed since it was outpoured. As yet the source whence it came is not visible, but we shall find it many miles away. Many have presumed that it came from Mount Taylor; but this is a mistake. This rough, clinkery lava is called by the Mexicans "malpais," a term with which we have become familiar from Humboldt's writings. We shall in due time and place describe it more fully; for throughout the adjoining regions the fields covered with it are many and large, and they increase both in number and in area towards the south and southwest, until the greater part of the country is mantled with it.

Here we may consider ourselves as well within the Plateau country. The scenery is strong and somewhat impressive, for the component masses of the landscape are all large, and for the most part of the true plateau type. Mount Taylor, however, is exceptional, for this is a great mountain, with a roughly conical peak, with long sharp tumbling spurs, deeply-incised ravines, and intervening buttresses. Still we find a few such elsewhere within the province and it is therefore not altogether anomalous. The wide expanses of featureless plains, the far-off summits of giant cliffs, resplendent with rainbow colors, the flat crest lines dropping in vertical palisades, the naked strata lined off at their partings, the bright yellowish or ashy soil, the brilliant sun-light and torrid heat, the blue haze of the atmosphere, like an ethereal veil between us and surrounding objects — all these are the true characteristics of the Plateau country, with which we have already become familiar in other portions of it. Before us it stretches for 400 miles, repeating its characters in forms that are ever the same yet not the same, which are uniform yet infinitely varied. The broader or generic features are constant, the specific features protean and full of contrast.

But let us follow the course of the railroad a little farther to the northwestward. It ascends the wide valley between the great palisade of red cliffs and the slopes of the Zuñi Plateau. The width of this valley varies from four to six miles, and beyond Bluewater Station (see map,



Julius Bien & Co. Lith.

EOCENE	CRETACEOUS	JURASSO TRIASSIC		CARBONIFEROUS		ARCHEAN	VOLCANIC	
		Jura (?)	Trias	Permian	Carboniferous		Recent Basalts	Tertiary Eruptives
E	K	J	T	Pp	P	A	Vb	Vt

GEOLOGIC MAP OF NORTHWESTERN NEW MEXICO

By Clarence E. Dutton
(FIELD-WORK OF 1884)

Scale 1:640,000 = 10 miles : 1 inch.

Contour interval = 200 feet.

Base from topographic work of the U. S. Geological Survey in 1881-3.

Plate XIV) the cliffs are very imposing. Between Grant and Bluewater the road crosses a wide expanse of malpais, which is naked in some places and in others is covered with blown sand and dust, forming a thin soil. The great cliffs to the north are Jura-Trias, capped with a heavy adamantine layer of quartzitic sandstone, which represents the basal member of the Cretaceous. The slopes of the Zuñi Plateau to the south are, first, Permian or lowest Trias, while higher up the Carboniferous forms the main flank. The declivity is gentle and its surface is heavily timbered, so that the eye sees little else than a forest. At length, 130 miles by rail from Albuquerque, we reach the Continental divide, at an altitude of about 7,300 feet. Beyond it the waters are gathered into the Puerco River,[1] a tributary of the Little Colorado (Colorado Chiquito). The heart of the Zuñi Plateau is still to the south, while to the north the red and variegated cliffs of the Jura-Trias have assumed grand proportions, not far below those of the magnificent fronts of the Vermilion Cliffs of Southern Utah. From the Continental divide the road steadily descends, and 25 miles westward the cliffs to the north suddenly end, their crest lines quickly descending to the general level and vanishing (Plate XIX). Here we cross a great monocline, dipping sharply to the westward, and enter once more upon the Cretaceous. But having nearly reached the western limits of the field we are to examine, we shall here leave the railroad and endeavor to gain some more extended views of the regions to the north and south of it.

Hard by this point is Fort Wingate, one of the largest and most important military stations in the Indian country, where troops are stationed in some force to keep watch over the populous Navajo Nation on the one hand and the more peaceful Zuñis on the other. Just south of the post and immediately above it rises the highest part of the plateau. From its summit we gain an overlook of the country far to the northward and westward. To the north there is comparatively little to attract attention except the great cliffs which we have already noted and which are, so to speak, close at hand. But the eye now ranges beyond their crest lines into a region which presents but little diversity. The land is for the most part flat and monotonous, its smooth surface barely broken by low ledges of sandstone and shale, much too insignificant to be called cliffs and mesas, nor yet sufficiently scoured by erosion to form bad-lands. From the crest of the great Jura-Trias cliffs, as far northward as we can see, the country is made up of horizontal Cretaceous beds, some high, some low, in that stratigraphic system.

[1] There are unfortunately within the limits of the region covered by the map given herewith two rivers named Puerco. One runs northeast of Mount Taylor and empties into the Rio Grande a few miles north of Albuquerque. The other is the one referred to in the text. It heads west of the divide, and belongs to the drainage system of the Colorado. The use of the same name for wholly distinct rivers and mountains was as common among the Mexicans as among the early American pioneers of the Northwest, and is very apt to lead to confusion. The river first mentioned in this note will be called Puerco East and the other Puerco West.

Probably, too, some of the more distant ground in this direction is made of Tertiary beds; but this remains to be inquired into. Faintly outlined against the horizon, and nearly 100 miles to the northeastward, far beyond the limits of the accompanying map, there rises a long, flat plateau summit having, I should judge, a length of over fifty miles. It is the Nacimiento or Jemez Range. It is a repetition of the Zuñi Plateau on which we stand. So far as can be judged by Dr. Newberry's description, it has the same general features, some of which, however, are more pronounced.[1]

To the northwestward, and only 40 miles away, rises a conspicuous plateau mass of much smaller though still considerable dimensions. It is named on the maps the Choiskai Plateau (more frequently pronounced Chusca and so written on older maps), which is one of the sacred places of the Navajos. It is in fact a lofty mesa, composed of strata which are horizontal in the eastern and middle portions of the mass, but turn *upwards* as they approach its western verge. The upper portion of this mesa must surely be Tertiary, but the most diligent search failed to disclose a single fossil. Still I feel confident that its strata are of Tertiary age, for the youngest Cretaceous (Laramie) is far beneath them.

Still more to the northwestward and westward we look over a country which is greatly diversified, and where the rocks have been subject to considerable dislocation by faults and monoclinal flexures of the normal plateau type. Erosion has worked upon them remorselessly, carving out many bold irregular forms, the exact meaning and relations of which are not distinguishable at a distant view. Six to eight miles distant is the Nutria monocline, rolling up towards us and showing the ends of the Jura-Trias in serrated edges. This side of the monocline is Permian or Lower Trias; beyond it all is Cretaceous. Before I have concluded this paper I intend to carry the reader some distance into these regions to the west to see what is there; but it is now more properly in order to take up as soon as practicable the description of the Zuñi Plateau on which we are standing and of its immediate purlieus. Yet, before taking up the description of the plateau itself, let us look hastily at the southwestern side of it and endeavor to gain a distant view of the region beyond its flanks. Only a few points need to be noted. The southern and southwestern side is simply a repetition of the northeastern in inverse order. There is the gently sloping flank, descending into a broad valley parallel to the axis of the plateau, and on the farther side of the valley rise up the Jura-Trias cliffs facing us. Beyond their crest line the Cretaceous strata reappear, stretching far

[1] Geological Report by J. S. Newberry, exploring expedition from Santa Fé to junction of Grand and Green Rivers in 1859, Capt. J. N. Macomb commanding. Mr. Oscar Loew has also given some hasty notes of this range in Lieutenant Wheeler's report for 1875. (Annual Report upon Geological Explorations and Surveys West of the One Hundredth Meridian, by George M. Wheeler, first lieutenant of Engineers, being Appendix LL of the Annual Report of the Chief of Engineers for 1875. Washington, 1875.)

away into the unknown regions to the southward. Thus, then, the Zuñi Plateau is simply a great swell in a vast regional expanse of Mesozoic rocks, breaking for a brief space the continuity of that system of strata. From its broad surface the Mesozoic has been denuded, leaving the edges of the strata more or less upturned to face it roundabout on all sides in rainbow cliffs. Away from the plateau the strata resume their horizontality and the Cretaceous becomes again everywhere the surface of the land. Vast and imposing is the expanse of this mighty Cretaceous system. If we could rise in a captive balloon 2,000 feet above this standpoint, the radius of vision would embrace more than 20,000 square miles covered with it. Yet it is but a trifle in comparison with its whole extent, which embraces half of the North American continent. Its thickness is equally matter of wonder. Whence came this stupendous mass of material?

THE STRATIGRAPHY.

The strata of the Plateau country are remarkable for their homogeneity or persistence of lithologic characters when considered with reference to their horizontal extensions. But when considered in the vertical sense they are almost as remarkable for the lithologic contrasts to be found among them. Each great group preserves its characteristics with singularly small amounts of variation from place to place, but the several groups differ as much as possible when compared with one another. The study of the geological features of the western border of the Plateau province during five successive seasons had produced in me a deep impression of the powerfully marked individuality of each group. The aspect—the colors, sculpture, composition, relative mass—of every one of them constituted a range of associations as distinct from every other as those which we experience in traveling from mountains to plains and from verdant plains to lifeless deserts. But the Trias of one terrace or plateau was the Trias of every other, and all were alike. So, too, was it with the Cretaceous and the Carboniferous. When I entered the southeastern border of the province, nearly four hundred miles distant, it seemed so like the western border that it was at first perplexing to decide whether there were any important differences in the lithology of equivalent horizons as between the two sides of the Plateau country. Some weeks of travel and study disclosed differences of detail sufficient to forbid at first any unreserved attempt to diagnose the formations peremptorily by their mere lithologic aspects, as we had been in the habit of doing on the other side. But the examination showed that by altering the criteria a little it was as safe here as there to run by lithologic characters when they had become familiar. They were found to be quite as strongly marked and individualized and in nearly all cases quite as persistent over wide expanses of territory.

In this portion of the Plateau country the fossiliferous rocks are all included between the middle Carboniferous and the summit of the

Wasatch Eocene. The lower Carboniferous, Devonian, Silurian, and Cambrian do not occur, and the base of the upper Carboniferous is seen to rest upon the granites and schists of Archean age. There is considerable uncertainty about the upper limit of the local strata; but the probabilities are great that it is as I have stated it, viz, the summit of the Wasatch beds. Between these limiting horizons we have the following major groups of strata: Upper Carboniferous, Permian, Jura-Trias, Cretaceous, and lower Eocene. They will be described in ascending order.

(1) The Carboniferous strata of the Plateau country have been divided into two portions, an upper and lower. To the lower portion the local name of the "Red Wall Group" has been given and the upper portion has been named the "Aubrey Group." The Red Wall takes its name from the great vertical escarpments which its most massive member presents in the cañons of the Colorado. In the Grand and Marble Cañons especially a band of limestone from 800 to 900 feet thick constitutes the face of the principal vertical cliff and becomes the most impressive stratigraphic feature of those great chasms. It has always been spoken of as *the* Red Wall. Its lower Carboniferous age has been well ascertained. Above and below it are numerous bands of limestone and calcareous sandstones belonging to the same group and always classed with it. While it is always found at the exposures of its proper horizon in the other parts of the Plateau country, it is plainly wanting in the district we are about to study, and its absence is certainly a striking fact. It appears to be absent also from the Nacimiento Range northeast of the Zuñi Plateau, where the upper Carboniferous rests upon the Archean just as it does here. In Southern and Southwestern Colorado, however, it is usually found in its proper place. The conclusion seems obvious that it was never deposited here, and that this locality was a land area in early Carboniferous time.

The upper Carboniferous or Aubrey Group is usually subdivided into two portions, an upper and a lower Aubrey. This subdivision is quite proper as well as convenient, for the two portions are strongly contrasted with each other in their lithologic features and in the topography to which their erosion has given origin. The lower Aubrey consists of bright red sandstones throughout, deposited usually in rather thick, and less frequently in moderately thin, layers. They are much alike in all outward respects, color, texture, and grouping, and in the erosional forms sculptured out of them. They are very fine grained, without traces of conglomerate or coarse shingle or gravels; and having a calcareous cement they weather easily and break down into very fine red sand. Fossils are scarce, but may be found here and there in sufficient quantity and distinctness to identify their age. These fossils, so far as I have seen, are the same as those which abound in the beds above them.

The upper Aubrey is composed largely of sandstones, but they have a very different aspect from those below. In color they are yellowish-brown, and the cement, instead of being calcareous, is siliceous, in fact a regular chert. These sandstones, in their final induration, seem to have been subjected to some process by which soluble silica has been deposited within them in great quantities, whether by the solution of the quartz of the granules of which the sediment was originally composed and their subsequent reaggregation, or by "epigenesis," I can only conjecture. These sandstones are often conspicuously cross-bedded, and the silicification of the rock has in no way obscured it. They have acquired a most obdurate character as against weathering, and yield only to the corrasion of streams or to the undermining of the ledges which they form, and to an inconceivably slow solution of their siliceous contents by atmospheric waters. There are several bands of these adamantine sandstones, and intercalated with them are three or four thick beds of pure limestone, containing an abundance of fossils of many and characteristic species.

While the Mesozoic strata of this district show some differences in comparison with those north of the Grand Cañon, the upper Aubrey shows none, except in thickness. Its cliffs in the upper wall of the Grand Cañon and those overlooking the granite of the Zuñi Plateau are so similar that it is hardly possible to doubt that their materials

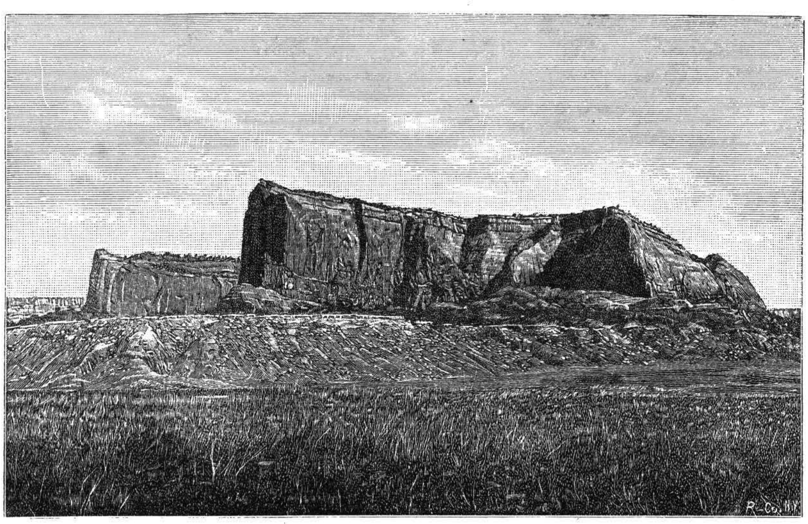


FIG. 1.—Wingate sandstone; the equivalent of the Vermilion Cliff sandstone of southern Utah. Photographed on wood and engraved.

came from the same source and were deposited under the same conditions. In the former locality they are thicker in about the ratio of 5 to 3, and this ratio holds good, not only for the Aubrey series as a whole, but for all its subdivisions and principal members. In the Grand Cañon the thickness of the Aubrey is about 2,000 feet; here it is about 1,200.

(2) The Permian series of the Plateau country has always been a troublesome one to the stratigraphist. That it exists there has been established with as fair a degree of certainty as paleontologic evidence will admit, by the researches of Mr. C. D. Walcott, who has found what are regarded as distinguishing fossils north of the Grand Cañon.[1] During the last season I found near Fort Wingate several specimens of *Bakewellia* and an attenuated form of *Myalina*, corresponding to the forms of the latter genus which are common in the Permian, but the strata assigned to that age are not fruitful in fossils. They are well separated lithologically from the Carboniferous below, but no really satisfactory separation from the Trias above has yet been made. Mr. Walcott has assumed a provisional upper limit at a well-marked, coarse sandstone, occurring near the southern boundary line of Utah, to which Powell gave the name of Shinárump Conglomerate. Curiously enough, this same Conglomerate, with identical features, occurs at Fort Wingate, and, indeed, wherever its horizon comes to daylight throughout this region.[2] Mr. Walcott's division is an arbitrary one, but is probably justifiable under the circumstances, because at the base of the Shinárump Conglomerate we often find one of those peculiar unconformities by erosion without any unconformity of dip. It is necessary to make a division somewhere, and this is the only "bench-mark" which is readily identifiable. It will have to answer the purpose until a better one can be found.

The Permian beds are distinguished for their dense and highly variegated colors—chocolate, maroon, dark brownish reds, alternating with pale, ashy gray or lavender colors. They are sandy shales, containing gypsum and selenite in abundance, with here and there thin bands of limestone. It runs more to thin, sandy shales than anything else. In its upper portions it contains a great abundance of the silicified trunks of large coniferous trees. This characteristic, too, is common to both sides of the Plateau province, and is also met with in all intermediate

[1] *Lingula mytiloides*, *Discina nitida*, *Orthis* ——? *Rhynchonella Uta*, *Nucula*, two species; *Ariculapecten*, three species; *Myalina*, four species; *Naticopsis*, two species; *Pleurotomaria* ——? *Macrocheilus* ——? *Cyrtoceras* ——? *Goniatites* ——? *Nautilus* ——? *Pleurophorus* ——? *Schizodus* ——? *Bakewellia parva*, and two other species; *Pteria* ——? *Mytilus* ——? *Rissoa* ——? *Pentacrinus* ——? and *Pileolus* ——?

[2] The persistence of this formation is indeed most extraordinary. A very coarse, almost conglomeratic sandstone is about the last kind of bed that one would have expected to find preserving any sort of constancy over a great area. Yet this member, which has an average thickness of hardly 50 feet, is found all over the Plateau country, so far as we yet know. The Potsdam sandstone of the Eastern States and Mississippi Valley is often spoken of as a remarkably persistent formation, but it changes its characters very notably from place to place, while the Shinárump Conglomerate keeps its aspect unaltered wherever it spreads. This would have been less remarkable if it had been a limestone or a fine-grained sandstone or shale. It is very perplexing when we attempt to conjecture how such materials could have been distributed so uniformly over such immense areas.

exposures. It is a common saying that there is more petrified wood in Arizona and Western New Mexico than living wood, and there is no great exaggeration in the statement. The Permian formation here is considerably thinner than in Southern Utah, being about 450 feet against 800 feet or more near the western border of the Plateau country.

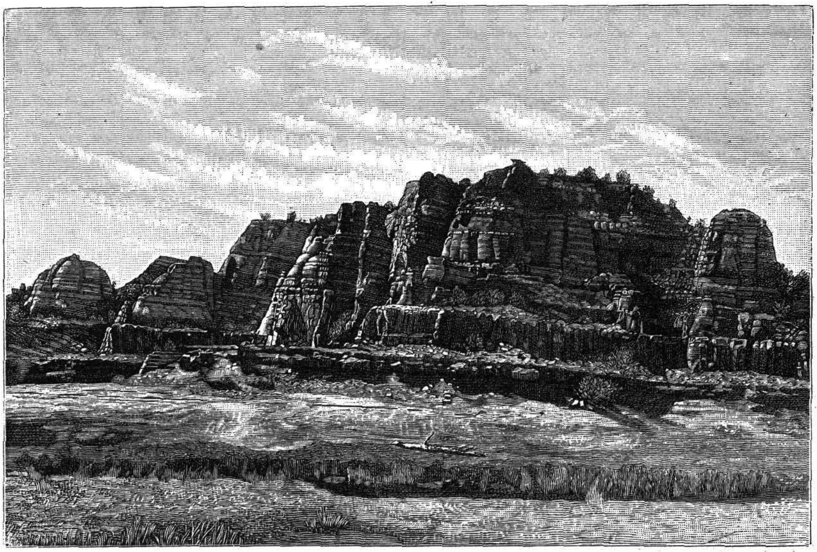


FIG. 2.—Wingate sandstone, with many beds and partings; the same horizon as that shown in Fig. 1. Photographed on wood and engraved.

(3) The Triassic system of New Mexico cannot be correlated so easily with its cognate beds in Southern Utah and the Grand Cañon district as the Carboniferous and Permian. In the former region it has yielded but few fossils, while in the latter it has yielded none at all. We have here as well as there only an arbitrary provisional horizon for its base, and we are if possible still more uncertain where to assign its summit. The paleontological doctors disagree, and who therefore shall decide? It all hinges upon the question whether the Jurassic system has any representatives in this region. If not, then the summit of the Trias can be established at once. But if the upper portion of the enormous series of sandstones and gypsum beds which lies between the Shinárump Conglomerate and the lower Cretaceous sandstone is Jurassic, the problem must wait for a solution. But let us first describe the strata themselves.

The coarse sandstone, equivalent, I believe, to Powell's Shinárump Conglomerate, will be for the present the provisional base of the series. Above it lie about 650 feet of dark, strongly colored sandy shales abounding in selenite and silicified wood. These shales resemble so exactly the Permian below that it is quite impossible to distinguish them lithologically. In color, texture, bedding, and variegation they are absolutely the same, and in order to know "which is which" it is necessary to find the coarse sandstone member. If the beds are above it they may be relegated to the Trias; if below it, to the Permian. The only fossils it has yielded are plants and a few Saurian bones. The former have been pronounced by Newberry Triassic and the latter are regarded by Cope as being of the same age. Above these dark shales lies a series of lighter colored, pale, dull-red shales the thickness of which I had no opportunity to measure satisfactorily. They weather so easily that they are always covered with sand or soil and are seldom exposed, but as nearly as could be inferred their thickness is about 800 to 900 feet. Two thin bands of hard limestone, only four feet and three feet, respectively, in thickness, were noted, and after spending many hours in searching them for fossils, I had my labor for my pains. No semblance of a fossil could be found.

Next in order comes the most conspicuous stratigraphic member of the whole region. It is a massive bright red sandstone. Out of it have been carved the most striking and typical features of those marvelous plateau landscapes which will be subjects of wonder and delight to all coming generations of men. The most superb cañons of the neighboring region, the Cañon de Chelly and the del Muerto, the lofty pinnacles and towers of the San Juan country, the finest walls in the great upper chasms of the Colorado, are the vertical edges of this red sandstone. It is in reality a group or sub-group of sandstone, in which the lines of bedding are generally, but not always, effaced. Sometimes, however, the partings are wholly obliterated, so that the edge of the en-

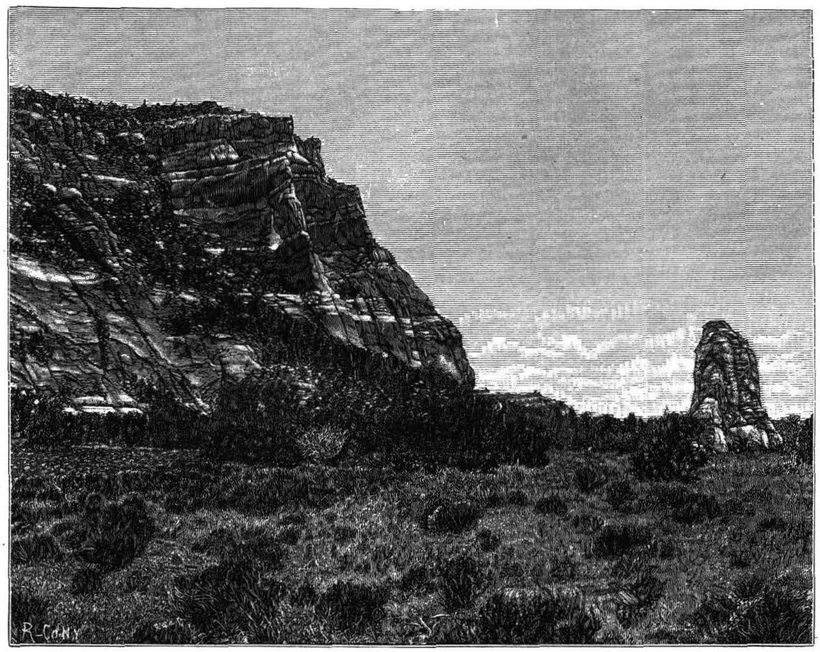
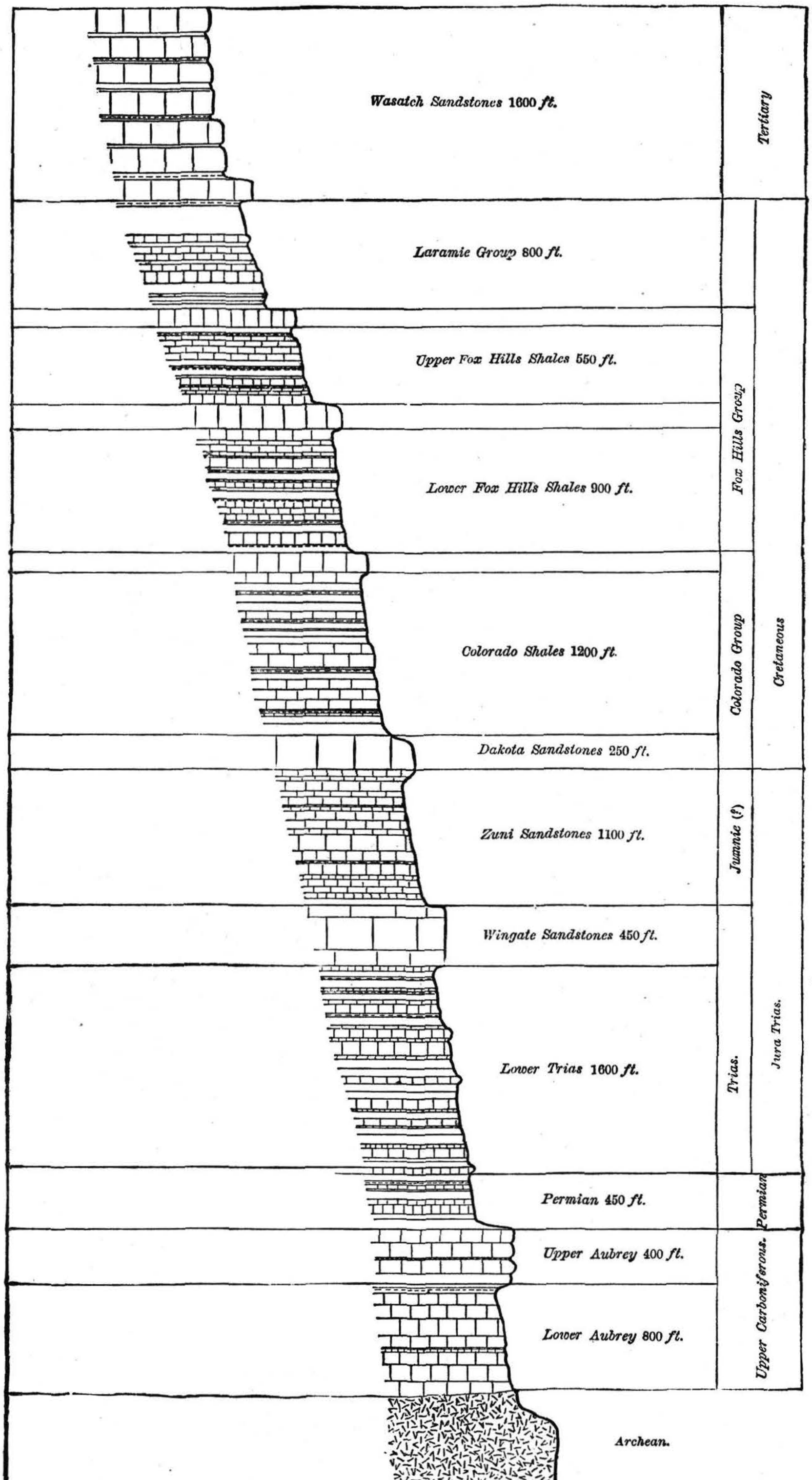


FIG. 3.—Zuñi sandstones, consisting of the upper members of the Jura-Trias system. Photographed on wood.



GENERALIZED STRATIGRAPHIC SECTION, ZUÑI PLATEAU.

tire sub-group is presented as a single indivisible member. Sometimes a portion of the partings is effaced, and a part is so presented. Sometimes partings are seen to divide the whole of it (Fig. 2) into a series of beds varying in thickness from a yard or two to 20 feet. Most frequently there will be at least 250 feet presented without subdivision and as a vertical wall (Fig. 1). This formation is without much doubt the equivalent of the Vermilion Cliff series in Southern Utah. But its aspect is somewhat different. We can, however, trace the transition of its outward features by a slow gradation over the intervening country. The thickness of this subdivision, which I have named provisionally in my field-notes the Wingate sandstone, varies much from place to place. In the immediate vicinity of the Zuñi Plateau its thickness averages about 450 feet. To the northward and northwestward it attains from 800 to 900 feet.

(4) Above the Wingate sandstones comes another series of sandstones and sandy shales with occasional masses of gypsum, the thickness of which is also very variable, ranging from 800 to 1,300 feet. Of all the stratigraphic subdivisions, it is the most inconstant when traced from place to place. It is wonderfully banded and variegated in color. Many pages might be written descriptive of the changes of color which it presents, not only as between different beds in the same section but as between the same beds in different sections. Some of the color effects are weird and even amazing. This formation, like the Wingate sandstones below, sometimes has its partings effaced, and is presented like a great massive individual member, but not so as a general rule. Between Wingate and Zuñi, around the southwestern flanks of the Zuñi Plateau, it is texturally solid and homogeneous, and yet is divided up into alternating bands of bright red and white, like the American flag. The white looks as if it had been painted with pot and brush upon a uniform smooth red surface. Around Zuñi the whole mass is of a nearly uniform creamy white color, suggestive of the White Cliff sandstone of Southern Utah (Figs. 3 and 10). In Pyramid Valley, south of Manuelito, on the Atlantic and Pacific Railroad (see western border of the map), it is of a uniform leaden color, and when seen from above under a bright sun it produces an astonishing color effect. North of Fort Wingate it is broken up into a series of variegated beds of all conceivable colors. Yet the materials of these strata are the same throughout, fine sand with a calcareous and gypseous cement, with an occasional band or even a thick member of gypsum. The gypsum is most abundant near the top of the series, where it occurs sometimes in very heavy masses. Silicified wood is also abundant in this series. I have in my field-notes named these beds the Zuñi sandstones.

Altogether we have between the Permian and Cretaceous horizons about 3,500 feet of beds, mainly sandstones, with some gypsum beds and a few thin sheets of limestone. Can the whole of this great mass be Triassic? The question is one which the paleontologists must ultimately decide, but the fossils are so few and indecisive that they are hardly in a position to answer it. Dr. Newberry is inclined, with some reservation, to call the whole Triassic and to discard the Jurassic altogether. Professor Cope, on the contrary, attributes a Jurassic age to the upper portion. Dr. Newberry found at the summit of the series and just beneath the Cretaceous at Abiquiu a fine series of fossil plants which he confidently calls Triassic. But fossil plants have not always been in harmony with other paleontologic evidence. The whole question, however, must remain for a long time in abeyance. It is useless to expect a satisfactory answer until the evidence shall have been collated in sufficient quantity and force to warrant a confident opinion. General considerations, however, strongly favor a Jurassic age for those beds which lie above the Wingate sandstones. This view correlates well with what we find in other portions of the Plateau country. And if they are Triassic, then we have a considerably greater mass of rocks of that age in this portion of the province than in the western portion. This would be surprising, and wholly contrary to what we observe in the other formations, which certainly grow thinner from northwest to southeast. In consequence of the uncertainty about their age, I shall adopt the non-committal term Jura-Trias for the whole series lying between the Permian and the Cretaceous.

(5) It is difficult to conceive of two kinds of scenery more strongly contrasted than those presented in the Plateau country by the Cretaceous and the Jura-Trias respectively. The Cretaceous is a huge mass of sandstones and shales devoid of any striking color and rarely presenting any pleasing or impressive forms. Its scenery is tame and monotonous, and when the vegetation is scanty or of a specially arid character the prospects are dreary and repellent. The Cretaceous system in the district examined is the same, in all essential respects, with the equivalent series which has been so well studied by Dr. Hayden's survey in Colorado. In stretching southward it has undergone no material change. At the base we have the Dakota sandstone, which here, as elsewhere, is the most conspicuous and important individual member. It is a hard, obdurate mass, varying in thickness from 180 to 230 feet, and its broken edge almost always marks a great break in the topography of the country. It is usually found as the capping of some great mesa or terrace, for its adamantine texture enables it to resist the wear of erosion while the beds above it are readily dissolved away.

The Cretaceous series is so vast and at the same time so monotonous that in order to present its chief component masses in a way that will be readily comprehended we may resort to the following device: Imagine four members consisting of massive sandstones, the several members being from 100 to 250 feet thick. Imagine them separated from each other by masses of soft, thinly-bedded sandstones, sandy shales, marls, and limestones. Or, again, imagine 3,000 feet of these shaly and marly beds, with the massive Dakota sandstone (250 feet) underneath them, a second massive sandstone on top (125 feet), and two more similar massive sandstones (125 and 175 feet) inserted in the midst of the series. These sandstone members thus become planes of reference. Between the Dakota and the second one (in ascending order) we have some 1,200 feet or more of shaly beds; between the second and third nearly 900

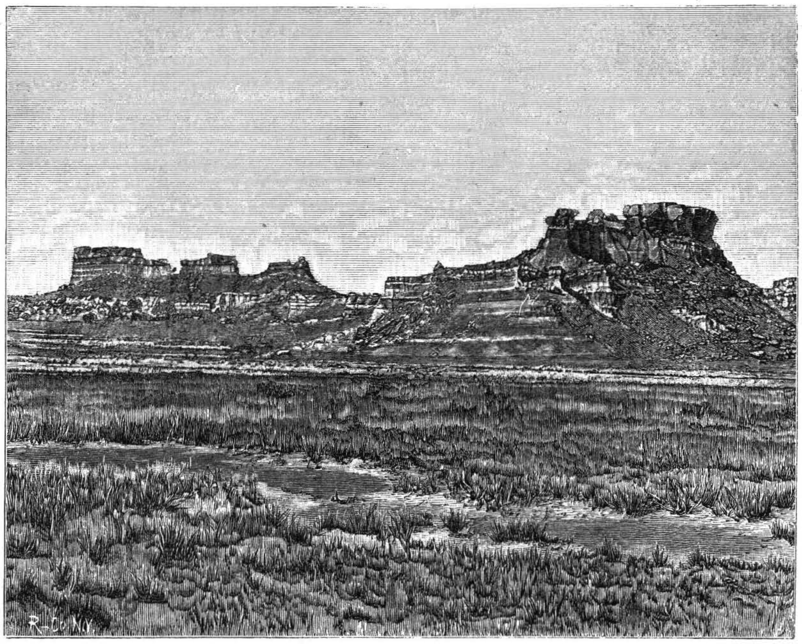


FIG. 4.—Buttes and mesas of the Middle Cretaceous. Photographed on wood.

feet; between the third and fourth 550 feet. This will include all the Cretaceous below the Laramie beds, which must be added to make the series complete. The thickness of the Laramie I do not know, but infer that it is not far from 800 feet. We have then the following scheme in descending order:

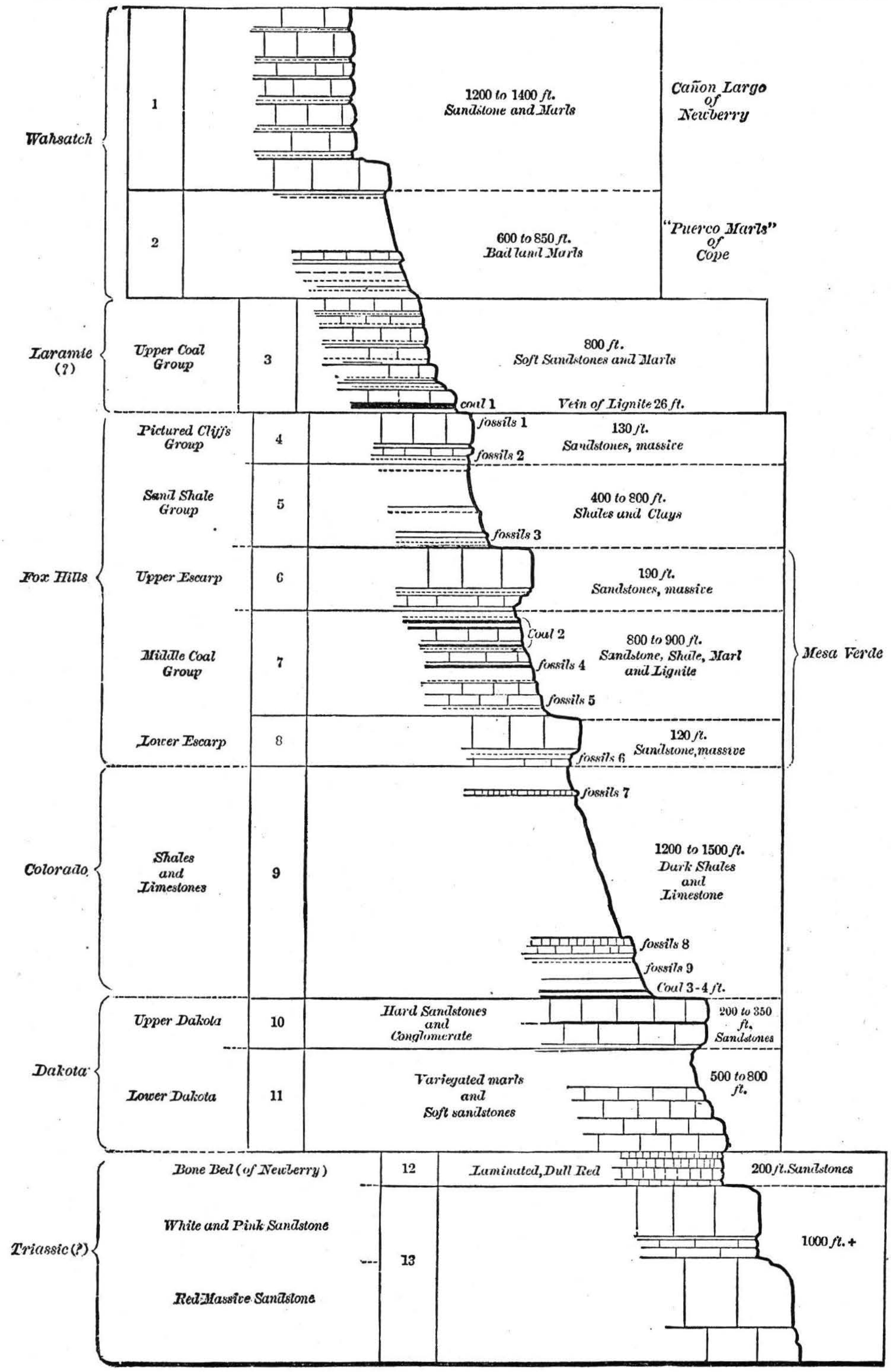
Cretaceous system.

	Feet.
1 Laramie group	800
2. Massive sandstones (upper)	125
3. Shales and marls	550
4. Massive sandstones	175
5. Shales and marls	900
6. Massive sandstones	125
7. Shales and marls	1,200
8. Dakota sandstone	250
Total	4,125

The above divisions are by no means based on paleontologic data. Quite the contrary. They only represent such subdivisions as the geologist sees in the topography and outward aspects of the beds. To investigate the fauna and flora and establish divisions upon the basis on which such divisions are usually made would, in this little district alone, involve several seasons' labor by an experienced paleontologist. The monotony of the series, the great inequalities in the amount of erosion, the similarity of the different portions, and the enormous mass of the series make it a difficult one to unravel. Fortunately, the shaly and calcareous beds generally yield fossils, sometimes abundantly, and with time and patience the subdivisions of the system can be satisfactorily made and correlated with those of adjoining regions. It may be of some interest to compare the foregoing description with the section made by Mr. W. H. Holmes (Hayden's Report for 1876—Ninth Annual Report U. S. Geological and Geographical Survey of the Territories) in the valley of the San Juan River, about 150 miles north of Fort Wingate. The agreement is very close, and Mr. Holmes's diagram is here reproduced for purposes of comparison. (Plate XVII.)

The entire series abounds in coal beds and bituminous matter. Much of the coal is quite workable and of fair quality. It is now mined on the Atlantic and Pacific Railroad, near Gallup, and is used exclusively in all districts roundabout which cannot be more cheaply supplied with coal of the same sort from other localities. The quantity of this coal is enormous, for it is found in many thousand square leagues of territory. It is not at all improbable that there is more coal west of the Mississippi than east of it. The quality, however, is somewhat inferior.

(6) The former existence of the Eocene in this district is rendered highly probable by the occurrence of a large remnant of sandstones in the Choiskai mesa only a few miles to the northwestward and a much larger one a little more remote lying due north. The latter locality, however, was not visited, but it has been identified by Professor Cope and other geologists attached to Captain Wheeler's survey. Its limits are unknown to me, and I have not ventured to attempt their expression upon the map. With regard to those upon the Choiskai mesa, two visits to them, one by myself, the other by my companion, Ensign O. G. Dodge, U. S. N., failed to bring to light any fossils, though diligent search was made. Of their Eocene age I have no doubt. By noting the dip and thickness of the Cretaceous system traced in two directions it was clearly seen that the beds on the summit of the mesa must belong to a much higher horizon than any others in the neighborhood. They differ also in character from the recognized Cretaceous, being chiefly hard obdurate sandstones, with a few softer marls and shales. They answer well to the descriptions given by Newberry, Holmes, and Cope of the Wasatch beds in the Cañon Largo to the northeastward. Undoubtedly, the Laramie beds are below them, but my journey over this ground was made under great pressure and I had not the opportunity to attempt the identification of the Laramie Group. The Wasatch beds are very thick, but as I do not know precisely where they are to be separated from the Laramie below I am unable to give the measure of them. They and the Laramie together have a thickness of 2,000 to 2,100 feet, and the Laramie can hardly exceed one-third of the whole.



GENERAL SECTION, VALLEY OF THE RIO SAN JUAN, BY W. H. HOLMES.

[Taken from Hayden's Report for 1876.]

CHAPTER III.

THE ZUÑI PLATEAU.

The platform named Zuñi Mountains on the map is not a proper mountain range. It is an elevation of the plateau type, produced by some uplifting force raising it considerably above the surrounding regions. On the northeastern side the strata rise by a gentle acclivity to its summit, where they become horizontal and continue so as far as the southwestern border. Then they decline again into the regions beyond. The summit of the platform is excavated into a broad valley by erosion, with remnants of the strata which once stretched across still remaining. The general trend of the axis of the uplift is northwest and southeast.

From the colored map it will be seen that the strata now covering the regions surrounding the plateau are successively terminated as they approach it. First, the uppermost, or latest formation of the country (Cretaceous) ends in a cliff which drops the profile of the land upon the Jura-Trias. This latter formation reaches farther inward towards the plateau, but is at length cut off exposing the Permian. Finally the Permian ends in like manner, leaving the Upper Carboniferous to form the innermost belt. Throughout a considerable portion of the plateau, the Carboniferous is cut off at the shoulder or crest of the main platform, and beneath it the gneisses and mica schists of the Archean appear in the heart of the uplift. That all the strata which appear in the surrounding country, but which are now absent from its flanks or its summit, once extended unbroken across its entire extent, is apparent enough to the geologist, but this will be adverted to hereafter.

It will be seen from the colored map (Plate XIV) that the successive belts of strata occupy much wider portions of the surface upon the northeastern than upon the southwestern side. The reason for this will appear from an examination of the sections (Plate XVIII). From the northeast the strata rise towards the summit by long gentle slopes, while upon a part of the southwestern flank they turn up suddenly, and at a high angle, in the Nutria monocline, a feature which will be examined in some detail further on. To the northwest the elevated tract diminishes in height and in breadth and finally vanishes completely. To the southeast it similarly vanishes, but more gradually; but its termination in this direction is considerably beyond the limits of the map, and therefore cannot be shown. In order to gain some more definite conception of the arrangement of the component masses, and at the same time to put this conception into relation with the processes which have made them what they are, let us endeavor to carry back the imagination to some period immediately preceding the action of the forces which have uplifted the plateau.

Early in Tertiary time the strata which are now absent from the surface of the uplift, but which appear cut off in the cliffs which surround it, were continuous across it. They were also very nearly horizontal. When the elevation of the plateau began and made progress, the summit and flanks were attacked by erosion. In accordance with a well known law, erosion acts with the greatest vigor where the declivity of the surface is greatest. This law, which depends upon a good many factors, and is quite complex when resolved into its components, has been admirably analyzed by my colleague, Mr. G. K. Gilbert.[1] Accordingly, after some marked elevation had been gained, the mass of the plateau was wasted by erosion much more rapidly than the surrounding lowlands. The Cretaceous and Jura-Trias beds have been denuded completely from its summit and flanks and now appear only around its base. The Permian rises a little way up the flanks throughout most of the periphery, but upon the northwestern extremity it reaches up as far as the summit. The Carboniferous forms the main slopes, and large remnants of it occur upon the summit platform; but these beds have been greatly ravaged by erosion, so that the underlying Archean is exposed in several places. It is obvious that such an extensive destruction of the strata required a long period of time for its accomplishment, and though the whole of it has been effected far within the limits of Tertiary time yet the results of the process are everywhere eloquent of antiquity. As the denudation went on the plateau-mass was pushed up higher and higher. And as the central masses rose they bent upwards the edges of the eroded beds on the flanks. The abruptness of this flexing of the beds is very variable, and is generally more conspicuous on the southwestern flank, where it gives rise to the Nutria monocline. This structural feature is so important that it will bear examination in detail.

THE NUTRIA MONOCLINE.

Upon the southern limit of the map and about opposite the middle of the plateau, the strata have an inclination of only 6° to 10° at the most. There is here a series of cliffs on the upturn of the monocline which face northeastward towards the plateau. They consist of the upper and very massive members of sandstone in the Jura-Trias series and just back of their crest-line the Cretaceous is seen. Not all of the Jura-Trias is exposed here, for the broad valley in front of them is well covered with alluvium, which conceals the beveled edges of the lower Triassic members; and where the rocky strata rise to view out of the valley, and further in towards the plateau, the Permian beds alone are seen. As we follow the trend of the monocline northwestward the dip of the

[1] Geology of the Henry Mountains.

beds steadily increases. The succession of basset edges of the Mesozoic beds shows a crowding closer and closer together, until the entire thickness of the Permian, Jura-Trias, and Lower Cretaceous is exposed in a belt of country not much more than a mile wide. At Nutria the inclination of the monocline reaches its maximum of about 75°. This abruptness continues thenceforward throughout the northwestward course of the flexure until near the end; the inclinations, however, diminishing to about 50°. In this part of the monocline there are some very curious details worthy of special examination. At Nutria the configuration of the strata is as shown in the diagram, Fig. 5. And the general appearance of the ground is represented in the picture, Fig. 6. Here we observe on the left (southwest) the Cretaceous strata coming horizontally towards the monocline and actually abutting against it.

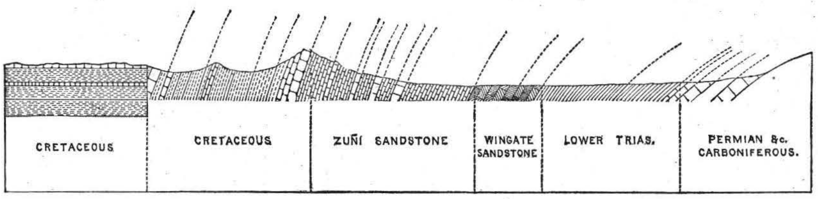


FIG. 5.—Section showing the positions of the strata in the monoclinal flexure at Nutria Spring, about 18 miles SSW. of Fort Wingate.

The great flexure seems to roll up out of the earth with its beds standing nearly vertically and with the broken edges of the horizontal strata walling against them. The members of the upturned Cretaceous which lie, or rather stand, farthest to the left, however, are younger in age and belong to a higher horizon than the surface stratum of the horizontal beds beyond; and, indeed, there are some 650 feet of these younger strata in the monocline which do not appear in the undisturbed series in the immediate neighborhood, though they occur in their proper place a mile and a half to the westward. This same configuration of the beds continues all the way between Nutria and the railroad. Fig. 7 is a diagram of the section where the Atlantic and Pacific Railroad crosses the flexure, near Gallup, and Fig. 8 shows the aspect of the ground on the west side, while Fig. 9 shows it upon the east side of the pass.[1]

These attitudes of the strata are indeed very perplexing. If we examine the minuter texture of the rocks we shall discover no evidences of compression or squeezing. We do observe, however, many indications of shearing stress, and these must inevitably have followed from the bending of the rocky layers. These traces are seen in the number-

[1] Dr. J. S. Newberry has given the same section in his geological report, page 68, included in the report upon the Colorado River of the West, explored in 1857 and 1858 by Lieut. Joseph C. Ives, and known as the Ives Exploring Expedition. He went through this pass in the year 1855. His representation is substantially the same as that given here. Mr. G. K. Gilbert also gives a section at Nutria in Vol. III, U. S. Geological Surveys West of the One Hundredth Meridian, Lieut. G. M. Wheeler in charge, page 553.

less minute joints where the curvature is great, and these may be regarded as so many differential slips. Sometimes, however, we find the sandstone layers bent without any of these traces of shearing. At Nutria, where the inclination is from 70° to 75°, there are no traces of differential slips or joints, and the layers of hard Dakota sandstone have been flexed without visible fracture. The massive red sandstones

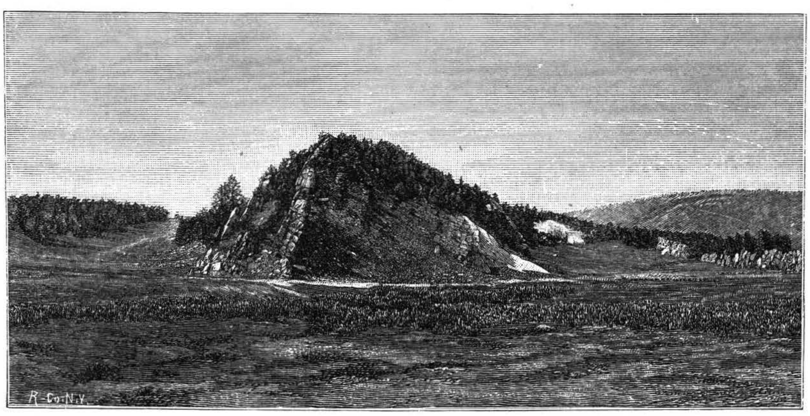
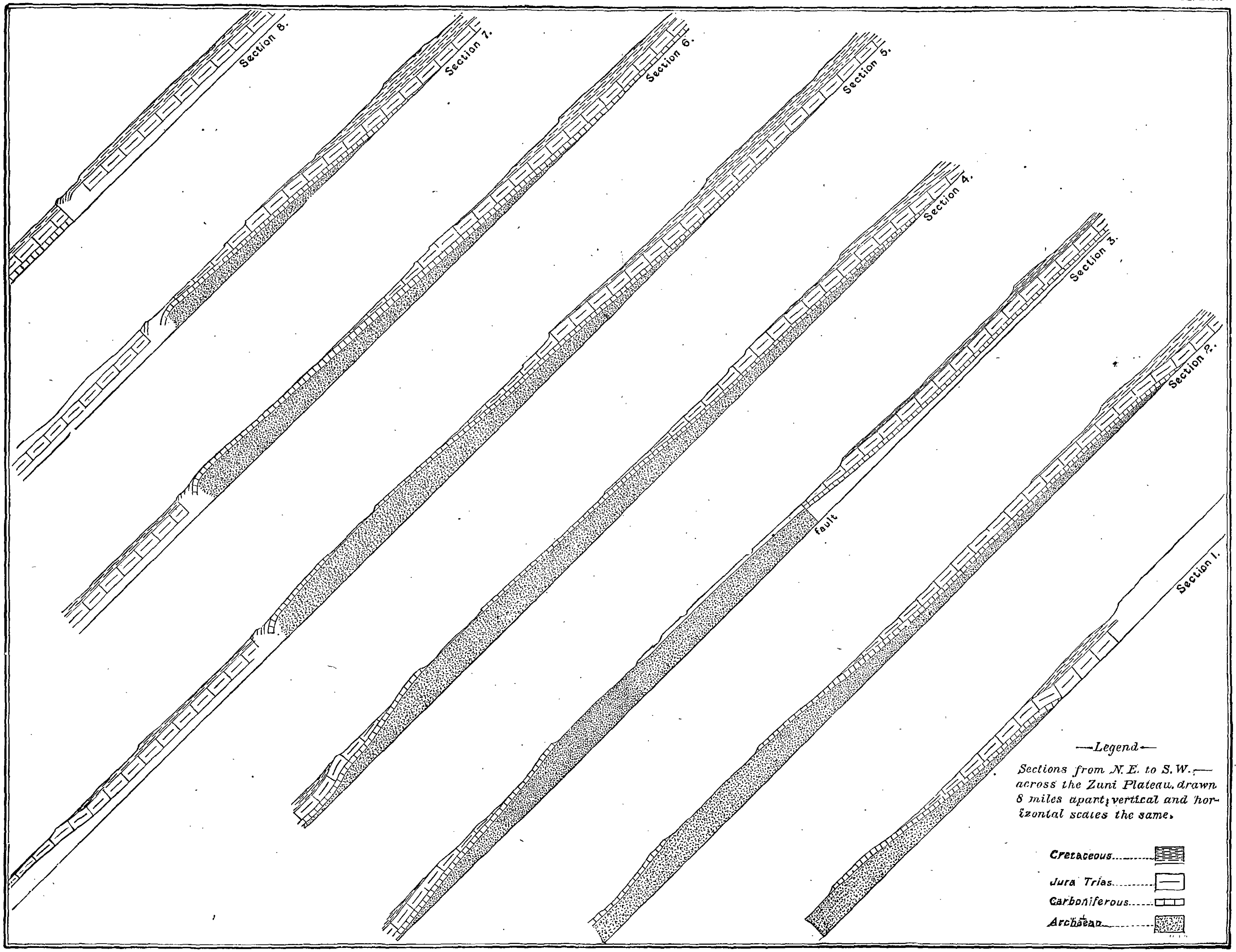


FIG. 6.—The monocline at Nutria. The summit of the hill is the nearly vertical outcrop of the Dakota sandstone; the right-hand slope is the edge of the Zuñi sandstone and the left-hand slope is the edge of the shaly beds overlying the Dakota sandstone. Compare this picture with the preceding section, Fig. 5. This picture is photographed on wood.

beneath are also exposed, and they too are apparently free from comminuted fractures. Thus we find in some places unmistakable indications of the action of those shearing forces which are set up when rocky strata are bent, while in other places the appearances indicate that the *plates* of rock have been bent as if they were plastic like metal.

The exposures are admirable, and the relations of the upturned beds to their horizontal continuations to the westward are recognized at a single glance. The first thought on seeing them takes the shape of the question: How was it possible for strata once horizontal to have been thrown into such positions? The inquirer, I think, will have to wait a long time for an answer. I have struggled with the problem, but without success. We may advert in this connection to some of the associated phenomena of faults in the Grand Cañon district which have been described in former works.[1] There it is a frequent occurrence for the edges of the thrown beds to turn downward as they approach the fault plane. This feature is conspicuous in the great Hurricane fault and in the West Kaibab fault. In the discussion of those displacements it was suggested that what is now the upthrown side of the fault was formerly the downthrow of a monocline of older age, and that a subsequent upheaval raised the present upthrown side while the older lift

[1] Exploration of the Colorado River of the West in 1869, 1870, 1871, 1872, J. W. Powell. Tertiary History of the Grand Cañon District, Monographs of the United States Geological Survey, Vol. II.


Section 8.
Section 7.
Section 6.
Section 5.
Section 4.
Section 3.
Section 2.
Section 1.
fault
—Legend—
Sections from N.E. to S.W.—across the Zuni Plateau, drawn 8 miles apart; vertical and horizontal scales the same.
Cretaceous
Jura Trias
Carboniferous
Archæan

of the monocline remained stationary. There is difficulty, however, in applying this somewhat arbitrary hypothesis to the curious dislocation of the Nutria monocline.

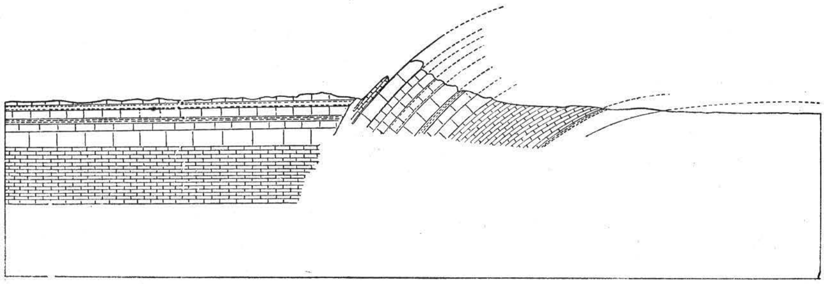


FIG. 7.—Section of the Nutria monocline at Mineral Spring, near Gallup, at the point where the monocline is crossed by the Atlantic and Pacific Railroad.

The method of resolution of the monocline towards the northwest is very simple. The displacement steadily diminishes and at last becomes zero. Just north of the railroad the Mesozoic strata, which are denuded from the uplift to the south of it, reappear, coming in one after another in a series of cliffs and terraces. The strata which terminate in these cliffs slope with a gentle dip to the north. The illustration (Plate XIX) conveys a much clearer idea than words can possibly do. From any very elevated standpoint south of the railroad and within a few miles of it one can easily see the whole structure. It is one of the fine spectacles of the Plateau country and highly characteristic of its scenery. The most conspicuous features are the great cliffs which stretch eastward as far as the eye can reach, rising in a succession of terraces, each marking some important subdivision of the Mesozoic series.

Let us now examine hastily the country which lies to the west of the Zuñi Plateau. The map shows that it is covered with a belt of Cretaceous strata fifteen to twenty miles in width. In traversing the road from Nutria to Zuñi we shall obtain a very good idea of a country made up of Cretaceous rocks. Just at the monocline we see the strata coming from the west in a strictly horizontal position until they abut squarely against the upturned beds in the flexure, as already described. This horizontality is approximately maintained far west of Nutria. But the country is deeply eroded into mesas, with sloping bluffs around their margins and with broad valleys and low plains between them. The strata rise very gently to the westward, bringing up lower and lower horizons, but the acclivity is so small that the eye does not detect it readily. The entire distance is through the lower part of the Cretaceous (Colorado group of Hayden), though occasionally we see a few hundred feet of higher beds occurring as remnants. About nine miles east of Zuñi the whole mass is suddenly upturned monoclinally. In this flexure the depressed side is the eastern and the uplifted side the western; just the reverse of the Nutria monocline. The inclination of the beds is at the most only 9° or 10°, and generally rather less. The drainage from the western slopes of the Zuñi Plateau is here gathered into the main valley of the Zuñi River, a tributary of the Little Colorado, which passes through the monocline in a gorge about 500 feet in depth, and in this gorge the upper part of the Jura-Trias comes into view. Upon

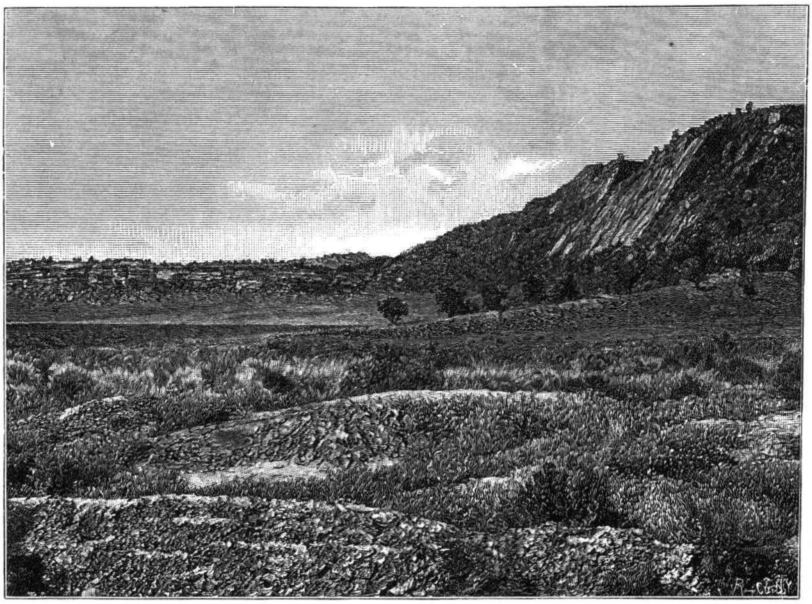


FIG. 8.—Nutria monocline at Mineral Spring; west side. On the left end of the picture the horizontal beds of the Cretaceous are shown and on the right end beds inclined at an angle of 55°. The horizontal members are seen upon the ground to abut against the inclined members. Photographed on wood.

the flank of the monocline the Cretaceous ends, being cut off by erosion, and the profile drops down upon the summit of the Zuñi sandstones (Jurassic ?). A little farther on it drops again to the Wingate sandstones (Upper Trias ?).

The map shows at this point a wide valley opening towards the west, floored with Triassic beds, while the Jura is seen on either hand. There is a marked difference when these two series (Zuñi sandstone and Wingate sandstones) are compared with their respective equivalent beds north of Fort Wingate. The former, the Zuñi sandstones, are here very massive, forming high cliffs, which are belted alternately red and white, while the Wingate sandstones below are broken into a series of rather thin beds with shaly and gypseous partings. North of Fort Wingate it is almost exactly the reverse. The Wingate sandstones are massive without partings, while the Zuñi series is broken up into numberless bands of highly variegated color and texture. A few miles farther westward, hard by the famous town of Zuñi, the upper sandstones have again changed their aspect. They have lost their belted colors and are now almost of a uniform creamy white or very pale gray. The edges stand in noble cliffs nearly vertical, and deep cañons are cut in the formation which are among the finest and most stately in this part of the country. Upon a mesa rising 1,200 feet above the plain and bounded by the steepest of walls are the ruins of the historic old town of Zuñi, one of the very few ruined pueblos of which there is even so much as a tradition. (Fig. 10.)

Southwest of Zuñi for many miles the whole country is composed of Jura-Trias and Upper Carboniferous, so far as now known; except of course those large areas which are overflowed with lava. In that direction I am not aware that the Cretaceous is seen again for several hundred miles.

The monocline which we have just noticed about nine miles east of Zuñi is a geological feature of the greatest importance. We crossed it at a part where its magnitude is least. The trend of the flexure is towards the northwest and its amount of displacement steadily increases. It crosses the line of the railroad a little west of the station Manuelito,

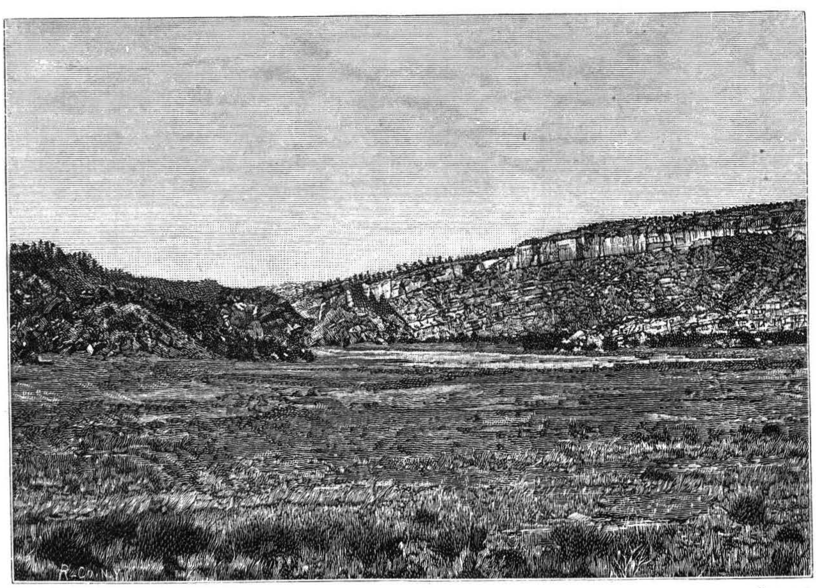


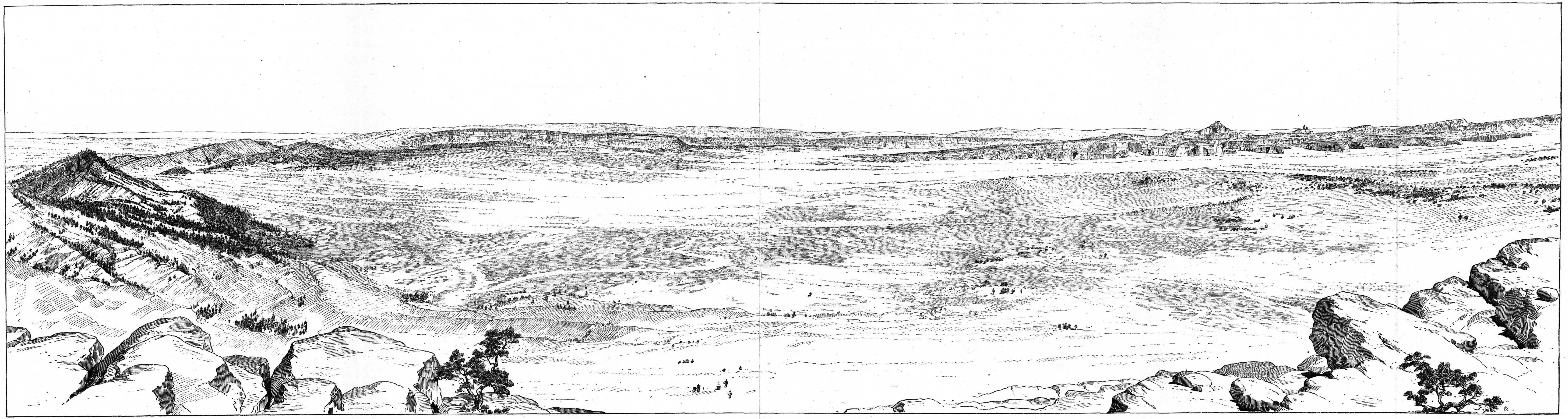
FIG. 9.—The Nutria monocline at Mineral Spring, east side, showing the inclined bed curving back to horizontality. Compare this and the preceding figure with the section Fig. 7. Photographed on wood.

upon the extreme western edge of the map. A little farther northward the flexure becomes much more abrupt and of much greater displacement. The inclination reaches more than 60°. Between Manuelito and Fort Defiance the Cretaceous is sharply upturned on the eastern flank, the edges of the whole Jura-Trias and Permian are quickly passed transversely to the outcrop, and the Carboniferous is rolled up high in air on the western or uplifted side. Defiance Valley[1] is a "monoclinal valley" parallel to the strike of the beds along the slope of this great flexure. I do not know as yet the full extent of this monocline, but have seen it as far north as the extreme northwestern corner of the map (Plate XIV), and it extends thence as far as the features of the country can be recognized. Its known length is 85 or 90 miles. The uplifted region to the west of it is for a considerable distance Carboniferous, with remnants of the Permian and Lower Trias. Thus the continuity of the Cretaceous system is for a considerable space interrupted by it, but it reappears far to the westward.

Thus we find that the Cretaceous system west of the Zuñi Plateau occupies a belt of country bounded on the west by the Zuñi monocline and on the east by the Nutria monocline, and the two great flexures dip towards each other. The intervening space, especially in the vicinity of the railroad, is complicated by several minor faults and flexures, but I have not worked them out. Their effects are not great, and they were not deemed of sufficient importance to occupy much time in studying them.

Turning the angle at the northwest end of the Zuñi Plateau, let us now follow the principal outcrops of the strata to the eastward. The long line of cliffs just spoken of now become the most commanding feature of the landscape as well as the most significant geologic fact. At the summit of the front or principal wall we find the base of the Cretaceous, consisting of an adamantine sandstone which makes a very resistant capping. Its thickness (the basal member only) is about 160 feet. Beneath it are seen the highly-colored variegated shaly sandstones forming the uppermost part of the Jura-Trias system, whether Jurassic or not is as yet uncertain. Still lower are much more massive sandstones of remarkable color, almost white or ashy, and showing no distinct partings for more than 200 feet. Still lower is the red massive sandstone of the Vermilion Cliff Trias, which, on the whole, is the most conspicuous member of the stratification in all the surrounding region (Fig. 1). It stands in vertical walls 250 to 300 feet high, without any apparent partings and without any cross-bedding. Its brilliant color, its massiveness, the bold and absolutely vertical faces, the smoothness of the wall, all combine to make it a very striking object of contemplation. It is, however, interrupted by wide breaches in many places, so that it is broken into a series of detached piles with a linear arrangement. As we approach the great cliff we find that this Vermilion Cliff

[1] Fort Defiance lies about four miles to the west of the western border of the map, very near the parallel of 35° 45′. The topographical sheet next west of the Fort Wingate sheet has been completed, and I was tempted to reproduce a part of it adjoining the geological map given herewith (Plate XIV), but the geological features are somewhat complex, and I have not seen the whole of the part so contemplated and could not give those features with the desired accuracy. I therefore abandoned the design. The geology in the neighborhood of this great monocline is extremely interesting, and I regret my inability to present it in detail.



PANORAMA OF THE NORTHWEST END OF THE ZUÑI PLATEAU.

sandstone stands more than a mile in front of the main wall, and that upon its summit there is a terrace, which, however, is so rugged by reason of the excessive inequalities of erosion that it is impracticable to travel far upon it without meeting some insuperable obstacle. In this terrace short deep cañons have been scored. They head at the base of the main wall, and are at first narrow and steeply, sometimes vertically,

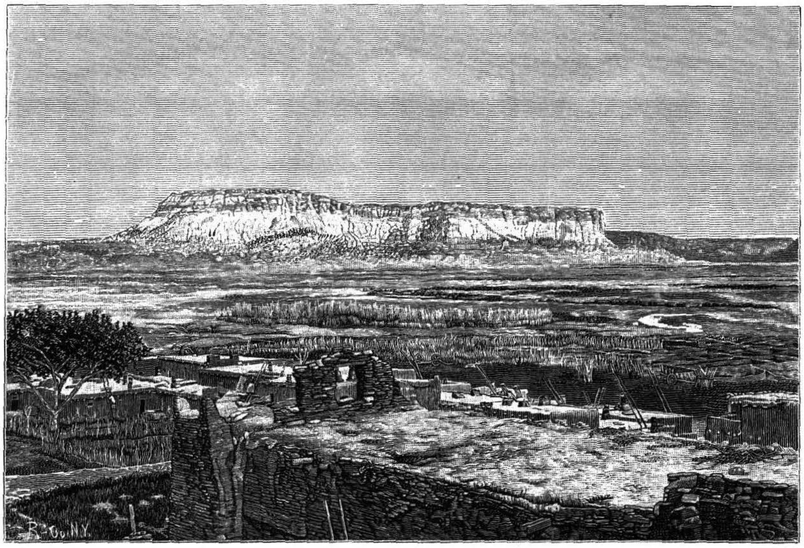


FIG. 10.—Toyalané; a butte composed of the upper members of the Jura-Trias system, as seen from the housetops of Zuñi. Photographed on wood.

walled. Farther out towards the plain they widen, sometimes to a considerable width. In several places the upper platform above the main palisade has been eroded away so as to lower the altitude of the cliff nearly one-half. In the widest of these gaps, a little west of Wingate, stands the remnant of eroded strata known by the name of "the Navajo Church," a conspicuous object from the southward. (Fig. 12.)

If we start from the crestline of the highest part of the cliff and proceed northward we shall find the strata dipping very gently in about the same direction as our course. The dip becomes more easterly if we choose more easterly starting-points, so that opposite Chaves Station, and still more decidedly opposite Bluewater, the dip is notably to the east of north. In our progress along the line of the dip we shall encounter successively higher and higher members of the Cretaceous series. They make their appearance as a succession of "bluffs" rather than cliffs. An interval of from one to two miles usually separates them, and each series carries the profile of the country up about as much as the dip of the beds since leaving the last ledge has carried it down. At a distance varying from eight to twelve miles from the southern crestline we come to the brink of a cliff facing northwards. Here the profile suddenly drops from 700 to 800 feet, giving us a very widely extended view. The country before us is a monotonous plain. Excepting the Choiskai mesa to the northwestward, there is no object to fix the attention except the faint featureless summits of far distant mountains just rising above the horizon. Here and there in the plain below may be detected the edges of sandy shales forming low bluffs, and these seem to be rather more common to the northeastward. The stratification in the plain below is nearly horizontal. Everything in sight is Upper Cretaceous except the higher part of the Choiskai, which I presume to be Tertiary. We stand therefore on a great mesa, terminated on its north and south sides by cliffs, its strata dipping from two to three degrees to the north, and composed wholly of Cretaceous deposits, those on the north side being younger than those on the south. Wherever we cross this mesa between the Nutria monocline on the west and the meridian of Bluewater on the east, the stratigraphy, dip, and topography will be substantially the same. The differences will be found only in minor features and details. Beyond the northern terminal escarpment the dip almost vanishes and the continued section will show nearly horizontal strata for many miles.

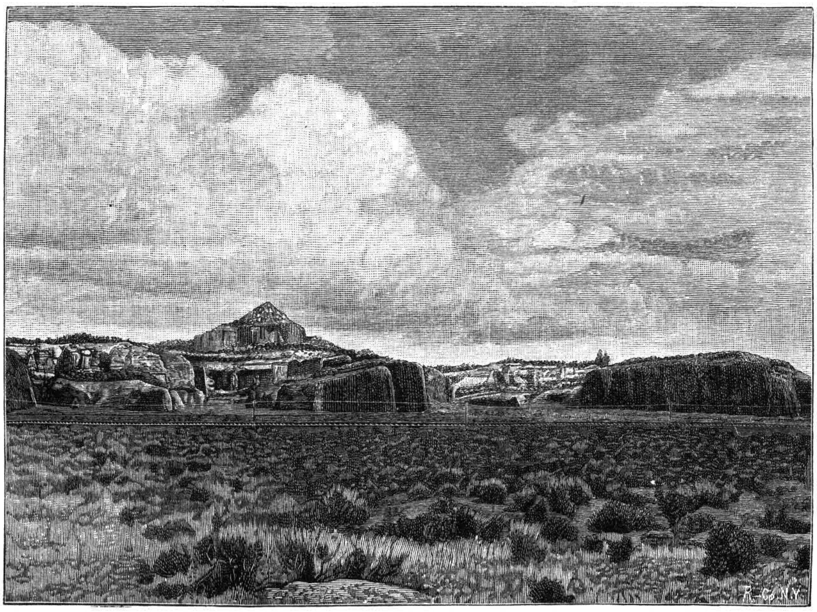


FIG. 11.—Pyramid Butte, near Fort Wingate, with promontories of the Wingate sandstone in front. The butte is composed of the Zuñi sandstones. Photographed on wood.

Let us now turn to the southern escarpment, which drops the profile into the valley through which the railroad runs. In the valley bottom the strata are much concealed by alluvia, but there are numerous outcrops. Wherever they occur they are Lower Trias. They are seen to have a stronger northward dip than the beds in the mesa above. In truth, as we approach the immediate slope of the Zuñi Plateau, the inclination of the beds slowly increases, until upon its ascending flank it reaches 10 degrees and sometimes 12 degrees. This large mesa, then, is a part of the general uplifted platform which constitutes the Zuñi Plateau and forms the outermost belt of the northeastern portion of its periphery.

Let us now follow this mesa to the eastward. Opposite Chaves Station the front cliff (facing the railroad) begins to decline in altitude until northeast of Bluewater it has sunken to the level of the plain and is for a time obliterated. Back of its line, however, with an interval of 6 or 7 miles, there rises the second cliff, composed of Cretaceous strata younger in age than that which has hitherto formed the capping of the first palisade. This second wall is less imposing than the first, but it has here a somewhat greater altitude than its continuation to the westward in the heart of the great mesa. At length, about four miles north of the town of San Mateo, it suddenly drops down, for a monocline here makes its appearance dipping sharply to the eastward. The course of this monocline is about N. 15° E., and the strata which have hitherto been conspicuous in the second palisade here roll down into the earth and disappear eastward beneath the border of the great volcanic mesa on which stands Mount Taylor. I have called this displacement in my note-books the San Mateo monocline. It is of no great magnitude, but is of some importance in the total structure of the district. Its northward continuation was observed for about ten miles from San Mateo, but was traced no farther, and its final resolution in this direction is unknown. Southward it continues across the plain and is lost in the broad promontory of the great volcanic mesa southwest of San Mateo.

Meantime, what has become of the Jura-Trias? A glance at the geological map will show the course of the outcrop of this formation. Northeast of Bluewater it descends to the level of the plain, and its junction with the base of the Cretaceous is mostly concealed for about nine miles by valley alluvium. Just north and northeast of Grant Station the map shows two detached lava-capped masses separated from the great volcanic mesa on which Mount Taylor stands. These two masses are separated from each other by a high, narrow col or saddle. The two are really one long tongue of sedimentary rocks and the col is formed by the eroding through of the lava-cap only. Directly in this col the junction of the Cretaceous and Jura-Trias appears, but it is exposed in a well developed monocline dipping eastward. The angle of dip is about 16° to 18°. The result is that the western fragment of the mesa-tongue consists of Jura-Trias strata, while the eastern consists of Cretaceous. The monocline, *before the eruptions of lava*, was beveled off smoothly by erosion, so as to form a nearly horizontal surface across the basset edges of the upturned strata. The monocline, then, is considerably older than the eruptions. Between the epoch at which the strata were bent and the epoch at which the lava was outpoured, a considerable amount of erosion was accomplished. North of the mesa-tongue the monocline quickly smooths out to a gentle dip, but southward it still prevails. Its course is a little east of south, and it just touches the sharp southwestern angle of the Mount Taylor mesa, where the edges of the Cretaceous beds beneath the lava cap are flexed up by it. Here the railroad enters the

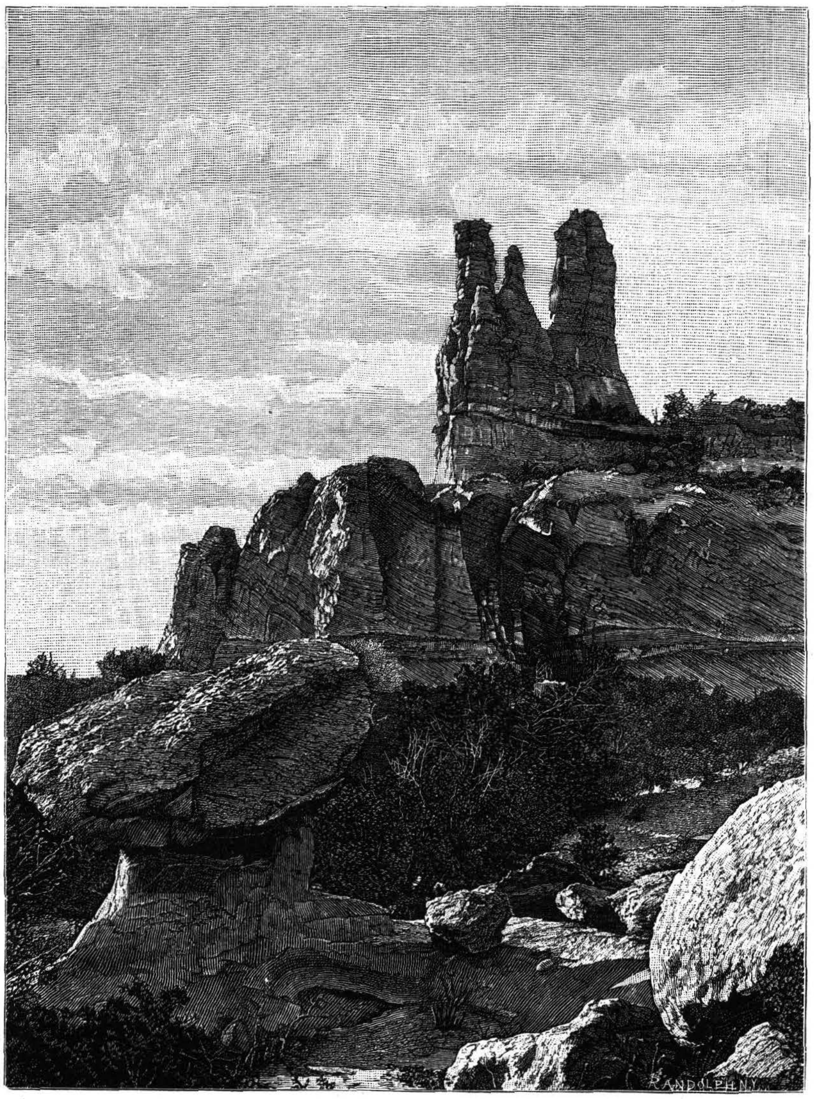


FIG. 12.—The Navajo Church, near Fort Wingate. The rocks are the upper members of the Jura-Trias, and strongly cross-bedded.

breach in the great mesas. Crossing the valley the monocline is seen entering the southern mesas near their western fronts, and the result is the strata in their western fronts are seen to have an easterly dip.

Extending southward from Grant Station, beyond the limit of the map, is a valley covered by sheets of very recent basalt. What lies beneath it can be easily inferred, though wholly hidden from the eye. Near the railroad a considerable part, and a few miles south of the railroad nearly the whole, of the Jura-Trias system is there. It has a dip to eastward, but always a variable one. This dip is greater near the main flank of the Zuñi Plateau and diminishes somewhat to the eastward, varying between 9° and 14°. On the eastern side of the valley, the base of the Cretaceous and 50 to 250 feet of the underlying system are exposed above the lava. Crossing the flows to the westward and reaching the base of the plateau, we find ourselves upon the summit of the Carboniferous, with here and there a trifling remnant of the greatly eroded Permian. In crossing the valley we have obviously crossed the basset edges of the whole or much the greater part of the Jura-Trias and Permian series, although they are completely masked by the streams of basalt.

I have thus described in some detail the configurations and relations of the strata immediately surrounding the base of the Zuñi Plateau. These are, so to speak, the approaches to it. It will appear from the description that the uplifting action affected a wide tract on the northern and eastern sides, and that its effects die out in a very gradual manner as we recede from the heart of the plateau in these directions. Upon the western and southern sides we find the uplifting force ending quite suddenly along the northern part of the Nutria monocline, while upon its southern parts it fades out about as gradually as upon the northeastern side. This is quite in accordance with what we find in similar uplifted plateaus or swells of the Plateau province. One side is generally more abrupt than the other.

It will be at once suggested that the strata in the mesa cliffs which face the plateau everywhere around its base once extended farther in towards it. There is no reason to doubt their former continuity over the entire area which the plateau occupies, nor that they have been removed by erosion. Whenever the elevating force which lifted the plateau has operated upon tracts now covered by Cretaceous strata, these beds have been turned upwards by it. At Nutria the Cretaceous is upturned at an angle of 73°, and in portions of the mesas south of Grant Station it is inclined at an angle of 12°; and to a less extent the same is true throughout the entire periphery of the plateau. Nor is there anything in the aspect and texture of the beds to indicate that the conditions of deposition in Mesozoic time, considered with respect to horizontal extensions, were interrupted locally in this vicinity; on the contrary, uniformity of conditions is disclosed, so far as concerns each particular stratum, whenever we trace it from place to place. Every observed fact is in harmony with the belief that the whole Mesozoic system once extended in full force across the platform from which it has since been denuded.

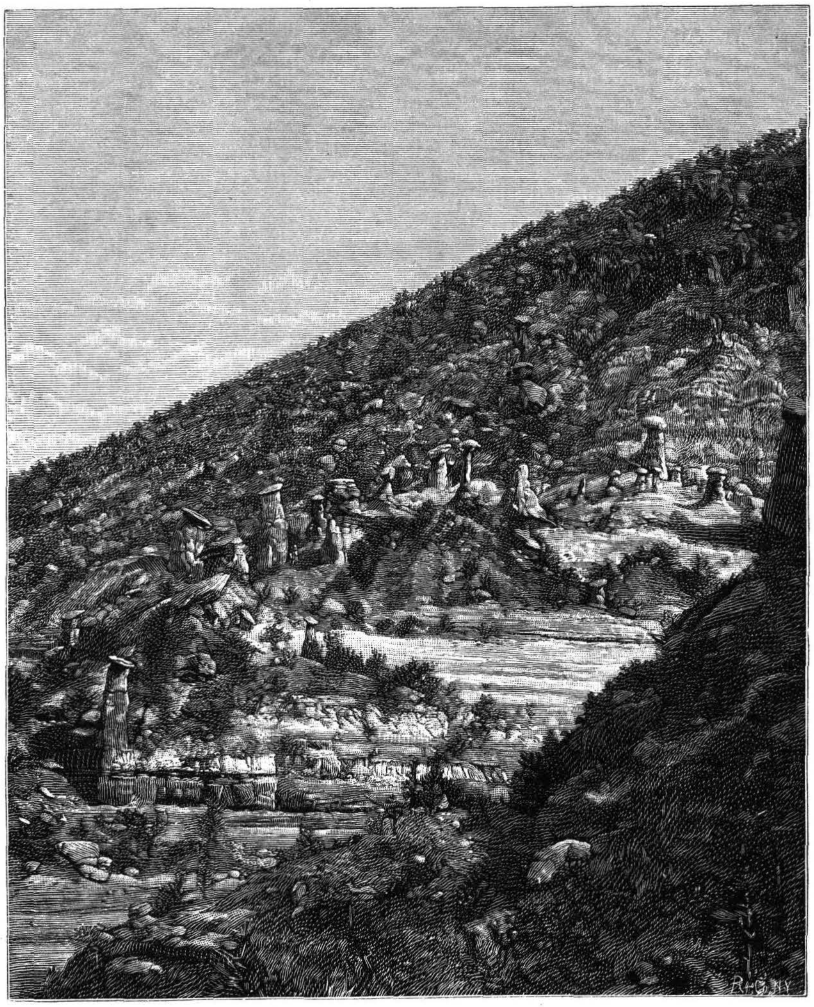


FIG. 13.—Eroded towers, capped with large blocks of sandstone, which had fallen from the Dakota sandstone, nearly a thousand feet above. The protection which these afforded to the softer calcareous sandstone on which they lay caused the gradual formation of columns by the slow dissolution of the surrounding rock. Photographed on wood.

Having examined briefly the details of the parts which surround the base of the plateau, let us now examine the flanks and interior spaces. The readiest means of approach will be found in the vicinity of Grant Station. A good road leads across the lava beds, or malpais, as it is locally termed, and a couple of miles beyond we find ourselves at the foot of the main slope. Here we are upon the summit beds of the Carboniferous formation. It is seen at once that the surface of this formation is the surface of the sloping flank of the plateau, which rises with an easy acclivity, varying somewhat, but averaging only 8° or 9°. From Grant Station may be discerned a cañon deeply incised into the sloping flank and descending towards us with a very tortuous course. At the mouth of the cañon the Carboniferous strata at once rise out of the plain, forming first a low ledge on either side, which increases steadily to a great wall as we ascend. The first beds encountered are hard sandstones of exceedingly obdurate character. Much of the silica is in the cherty condition, and its effect upon the weathering of the rock is noteworthy. Indeed this adamantine sandstone is such an important feature and its obdurate character has played so important a part in the development and shaping of the plateau that it is worthy of some remark.

If we examine attentively the surface of this rock we shall observe that its behavior under the degrading action of the elements, though not novel, is still uncommon in sandstones. When sandstones decay the ordinary mode is as follows: The cement which holds the grains of sand together is dissolved out, leaving the grains to fall asunder and to be easily washed away by the rains. But in the present instance the quartz itself forms the cement and the weathering of the rock proceeds by solution alone. The grains are not released by the removal of their cement, because the cement is as hard and durable as the grains. Of all erosive operations none can be slower than mere solution upon a homogeneous quartzitic rock. This upper member of the Carboniferous series forms a very large proportion of the surface in the flanks of the plateau, and we can now perceive the reason. The sandstones and shales of the overlying formations are far more perishable. When they have been eroded through to this adamantine member, the process is ther echecked except in places where the attack is not by weathering, but by the corrasion of running streams. Large areas have been completely denuded of all superior formations, leaving this one comparatively unharmed to form the general surface. To the action of corrasion, however, its resistance, though stubborn, is not widely different from other sand rocks of more soluble composition. Against the scour of running streams no rock is preof. Hence we find many shallow trenches cut in this hard sandstone by the streams, and a few deep ones. These streams are sufficiently numerous to roughen the surface considerably in a small way and occasionally have slashed it deeply by cañons. Where the cut is deep enough to have penetrated considerably into the softer rocks below, these readily weather, and the walls of the cut, wasting away, undermine the hard members above, which fall down in fragments. Corrasion and undermining are the processes by which this obdurate formation is finally subdued. As we proceed through this cañon the whole of the Upper Carboniferous series gradually comes up to daylight. To fix clearly in the mind the relations of things, it must be noted that as we ascend the cañon the strata also ascend at a much more rapid rate. In its upward course, therefore, the cañon steadily deepens and at length becomes quite pleasing. It is attractive on account of its ample width and the typically cañon-like profiles of its walls. Narrow cañons are usually devoid of all beauty or grandeur or of any kind of impressiveness whatever. This one attains finally a depth of nearly 800 feet and a width of a third of a mile. Its depth increases until the upper end is reached, when suddenly it emerges into open country. The walls swing at right angles, to right and left, and we find ourselves in the heart of the plateau. The country now before us is by no means smooth. Just at the upper opening of the cañon, strangely enough, is a stream of basalt, rough, clinkery, black and forbidding, and though it may not be quite so young as some others, is still very modern. Its source is not visible here, but we shall find it farther on. To the right and left stretches away the wall of Carboniferous strata facing the interior space of the plateau. Its altitude appears to be about 950 to 1,000 feet. Its course is from NNW. to SSE. In front of us the country is much obscured by the forest of great pine trees (*P. ponderosa*), but so far as can be seen it is a medley of low rolling hills, like the rolling prairie of Iowa. To the northwestward, three or four miles distant, rise several very large hills, one of which might be regarded as a small mountain. All of them are rugged and irregular in aspect and quite different in form and lineament from the topographic features we have hitherto been in the habit of contemplating. The country before us and the high hills on our right are composed of metamorphic and granitoid rocks, which are presumably of Archean age. It is much the largest of three distinct tracts of crystalline rocks on the plateau summit. Its length is not accurately known, since its southwestern limit lies far beyond the limit of the map and was not visited. But there is a length of about 30 miles in this particular tract that I know of from actual inspection. The width at the head of Zuñi Cañon and west of it ranges from seven to nine miles.

Passing around the lava beds and penetrating into the granitic area, we find the country heavily forested, covered with abundant soil, and green with luxuriant grass and herbage. The rocks, with one exception, disclose nothing which may not be seen in any tract of common gneisses and mica-schists, and any particular description of them would encumber the narrative to no purpose. The exception referred to is perhaps of some interest. We cannot travel a half mile upon these ancient schists without coming across patches of a peculiar-looking red rock which attracts attention at once. The first fragment hastily snatched up and examined was unhesitatingly pronounced quartz-porphyry. A few moments later doubts arose which grew into uncertainty as more and more of it was seen. Not until many specimens had been gathered in the course of several days and given such examination as is possible in camp, and their true positions observed on the following day, did the real nature of the rock become manifest. It proved to be a remnant of the basal member of the local Carboniferous sandstone metamorphosed in contact with the granite. There are all shades and degrees of metamorphism, from a sandstone slightly affected to a rock which cannot be rationally distinguished from a quartz porphyry. It is in no sense an eruptive rock, though it is easy to find specimens

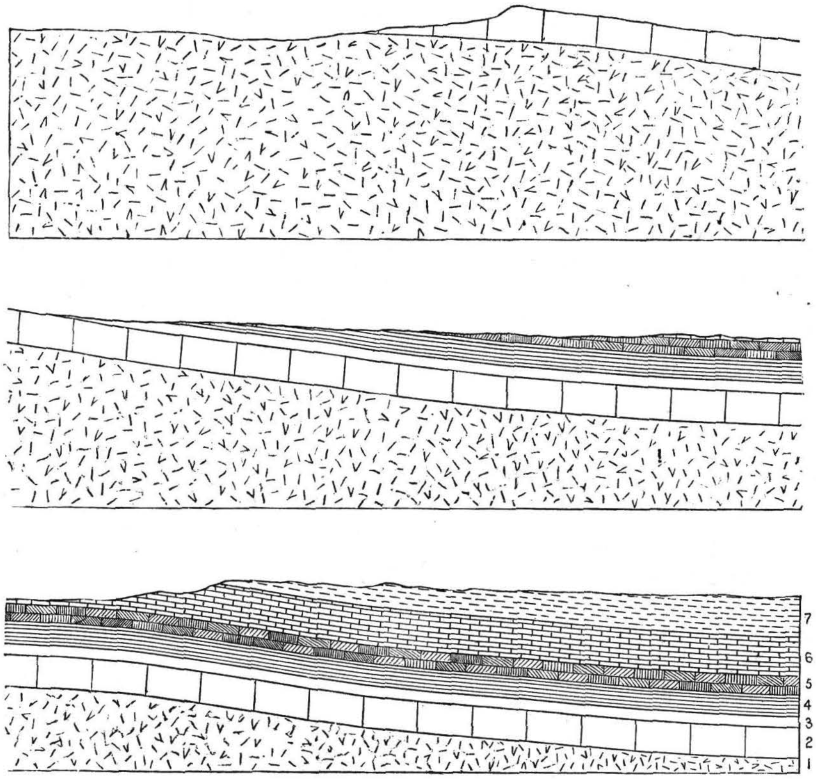


FIG. 14.—Section of the slope and base of the Zuñi Plateau near Grant Station. The section is drawn in parts, to accommodate the page; the right end of each of the two upper parts being continuous with the left end of the part below: 1, Archean; 2, Upper Carboniferous; 3, Permian; 4, Lower Trias; 5, Wingate sandstone, the equivalent of the Vermilion Cliff sandstone; 6, Zuñi sandstone; 7, Cretaceous.

which would, away from their locality, pass readily for elvanites. I have submitted a sample of the more completely altered variety of this rock to Mr. Diller, who has examined it and says:

The principal constituents of this rock are quartz and feldspar. A chief portion of the latter is microcline, although orthoclase with perthitic lamination and altered plagioclase are present. Quartz is the most abundant ingredient, occurring in the ground-mass as well as in porphyritic grains, which occasionally show the embayments common in rocks of this class. Scales of mica, magnetite, and epidote, resulting from alteration, are scattered throughout the rock. Although the mineralogical composition and structure are such as to indicate that it belongs to the quartz porphyries, glass inclusions and other phenomena which would prove its eruptive origin have not been discovered.

It is necessary to recall here that in this part of New Mexico no Paleozoic rocks older than Middle Carboniferous are known. Throughout the heart of the Zuñi Plateau, the Lower Aubrey[1] rests directly upon the Archean. This has been duly recited in Chapter II, which treats of the stratigraphy of the region. The fact is general throughout the summit portion of the plateau. The contacts are seen in numerous places and directly inferred with confidence in many others. The Silurian and Devonian systems are generally wanting in the eastern portions and border of the Plateau country, and whenever they occur they cut but a small figure. Their absence is therefore rather to be expected. But the vast Cambrian system, which presents such an imposing mass of strata in the western part of the Plateau Province, is equally absent here and to the northward.

At the northernmost part of the granitic area rises Mount Sedgwick. It is not a mountain of large proportions, though sufficient to be a conspicuous feature of the plateau. Around it are numerous ridges of Archean hills, which produce a rugged topography. On the summits of all these masses occur remnants of the metamorphic Aubrey sandstone, and they are found near the highest peak of Mount Sedgwick. In this there is a significance which will be adverted to presently. That it may be appreciated, it is necessary to look first at the margin of the Archean tract and study its relations to the Carboniferous cliffs which surround it.

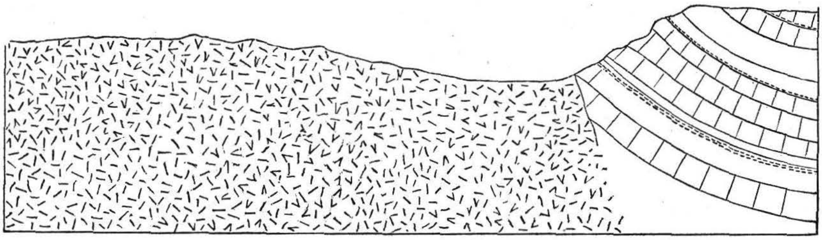


FIG. 15.—Section showing the contact of the Carboniferous with the Archean, the edges of the former being bent upward by a rising boss of granite.

From the summit of Mount Sedgwick we gain a comprehensive view of the Archean tract. It is seen to be inclosed by high cliffs of Carboniferous strata on all sides except towards the southeast, in which direction it stretches away into the distance, where its limitations cannot be discerned. These cliffs are in great part abrupt, in part broken down more or less into slopes, and in a few places cut by cañon valleys which let out the drainage. Zuñi Cañon is one of these drainage channels. At the northern base of Sedgwick is another, forming what is called the Bluewater Cañon, a deeper and finer gorge than the Zuñi. The drainage of the south side of the tract is towards the southeast

[1] The "Aubrey group" is the local name in the southern Plateau country for the Upper Carboniferous. It is divided into an Upper Aubrey and a Lower Aubrey. The Upper Aubrey consists of the hard, adamantine sandstones already spoken of, alternating with limestones. The colors are light yellow and gray. The Lower Aubrey is sandstone throughout in many layers, and always bright red.

along the margin (see map, Plate XIV), where the Carboniferous overlaps the granite. It flows past Agua Fria and beyond the limits of the map for about nine or ten miles, and then turns northward across the granite to enter the lava-flooded valley which carries it northward to San José.

The entire tract is seen at once to have been eroded by the removal of the whole local Carboniferous system, leaving the granite almost bare. Now, at the junction with the metamorphics, it is not uncommon to find the edge of the Carboniferous bulged upward. Let us try to conceive what the effect would be if the great cliffs 800 to 1,000 feet high everywhere surrounding the tract were quite hard, rigid, and unyielding, while the Archean beneath were soft and plastic. It is evident that the latter would slowly flow upward, as if squeezed out. Now this is what *seems* to have happened in a number of places, but by no means everywhere. Mount Sedgwick and the hills which ramble off from its southern slopes I think are of this character. Where the Carboniferous strata abut against it their edges are in many places considerably mangled, torn, and bent by the ascent of the granitic mass. The peak of the mountain is about 600 feet higher than the summit sandstone of the Carboniferous, and yet it carries metamorphosed fragments of beds which belong to the base of the Carboniferous. The entire arrangement and relative positions of the constituent masses roundabout give force and weight to the inference that the Mount Sedgwick mass is a small granitic boss pushed up in a plastic condition. Whether this was done before or after the erosion of the Carboniferous beds from the area which it occupies is a doubtful question; but the probabilities are that the two processes—the upswelling and the erosion—were in great part at least contemporaneous, and perhaps wholly so.

To further illustrate these local upward protrusions, let us endeavor to conceive the Archean platform to have been in most of its extent nearly as rigid as the Carboniferous rocks above, but that in several spots the softening and upswelling has been much greater than elsewhere. These conceptions accord well with what we see elsewhere. In other localities, however, where the Archean forms the core of a mountain range or swell, the whole mass (very nearly) appears to have been squeezed upward in a plastic condition. There is every indication in the Zuñi Plateau that the Carboniferous sediments, when their deposition began, found a smooth, level surface of eroded Archean rocks on which to rest. At present the portion exposed in the plateau is much deformed by unequal elevation. Mount Sedgwick and its vicinity exhibit the most extreme case of this inequality. But there are others. About ten miles southeastward, near Agua Fria, there are abundant indications of unusual upswelling in the plastic granite, and at several points considerable fragments of the lower Aubrey sandstones have been involved in the rising boss and have been roughly handled.

Another related phenomenon may be mentioned which is of still more frequent occurrence. It is not uncommon to find the edges of the basal members of the Lower Aubrey turned upward at the contact of the granite at a very sharp angle and sometimes much shattered. An instance of this is seen about half a mile from the head of Zuñi Cañon and in the direct line of its prolongation. If we follow southward the base of the great Carboniferous cliff which marks the boundary of the Archean tract we shall find the same phenomenon occurring again and again. Along this line there is everywhere manifest a tendency of the granite not only to carry up the whole body of superincumbent strata with it as it rose, but to *erupt* through it as a tough, viscous, or plastic mass. In some localities it seems to have flowed up so as to mold itself against the escarped edges of the sandstones to a height of 200 to 300 feet. This is most conspicuous in the vicinity of Sedgwick and its attendant hills. It might be suggested that this description is tantamount to a simple fault. It may be so, but in that case we have a form of fault extremely uncommon in the Plateau country. For the fault, if it be so viewed, is usually very short, of considerable displacement, and the upthrown or upraised mass is completely encircled by a dislocation which is a fault on one side and its nature unknown on the other sides. In short, I would prefer to invert the proposition, and say that the displacement is palpably a boss of Archean rock protruded upwards with every appearance of plastic yielding on three parts of its periphery, leaving the nature of the dislocation on the fourth side to be explained as best we may.

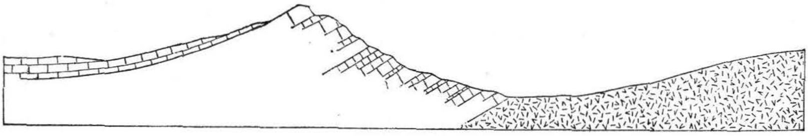


FIG. 16 — Contact of Upper Carboniferous with Archean.

In pursuit of a similar group of facts, let us proceed to the northwestern end of the plateau summit. The colored map shows a much smaller insulated tract of Archean rocks there, and it is full of interest. If we start from Fort Wingate and ascend the plateau by the road which leads through Nutria to the town of Zuñi, we shall find, about ten or twelve miles from the fort, an old ruined saw-mill. Just to the east of this mill rises a considerable ridge trending NNW. The ridge is cut through transversely by a gap, which gives an admirable natural section (Fig. 16). It is composed of Carboniferous strata turned up at a high angle and dipping fully 30° to the west. In this gap we may, within a space of 1,200 yards, cross the basset edges of nearly the whole Carboniferous series. But the aspect of these rocks is strikingly different, not merely in their attitude but in their whole facies, from what we have been in the habit of seeing where this formation is disclosed.

The brilliant red color of the Lower Aubrey is gone, and in place of it the beds show only a dark lack-luster brown. It is only by close scrutiny that we are really able to identify them. They have been metamorphosed—not to an extreme degree, but sufficiently to change their texture profoundly. The resulting metamorph in the sandstones is a porphyritic rock, similar to that encountered in the vicinity of Mount Sedgwick. In no other part of the plateau has the metamorphism affected so great a thickness of the Aubrey series, so far as I have observed. And yet a hundred yards beyond the western base of this monoclinal ridge the fossiliferous limestones of the Upper Aubrey lie quite horizontal and present their normal appearance. East of the ridge the granite at once appears and rises by a strong slope into a rugged, hill-crowned dome, higher than the crest of the upturned Carboniferous ridge. Here is another boss where the upswelling is conspicuous.

Following southward the contact of the granite with the Carboniferous the traces of metamorphism in the latter gradually disappear, the strata become redder and soon regain their normal appearance. They form a low wall facing the granite, which gradually increases in altitude, and at intervals we find it shattered and mangled. The edges turn up or are wrinkled or mashed, showing in many ways the action of some irresistible shearing stress. After a few miles, however, this ceases; the basal beds of the Lower Aubrey begin to reach out over the granite, and at length a thin layer of the lowest members stretches clear across the granite, becoming continuous with the same beds in the cliff upon the other side of the Archean tract. And we may now note another general fact: The metamorphism of the Lower Aubrey sandstones occurs, so far as I could observe, only at their contacts with those portions of the granite which have been bossed up. Wherever the vertical movement has been nothing more than the general elevation of the entire platform, no traces of metamorphism appeared, and the relations of the sandstones to the underlying granite were presumably the same as when they were first deposited and consolidated. I have been thus particular to describe these details, at the risk of becoming tedious and prolix, because I intend to utilize them hereafter.

It remains to describe those features of the plateau summit which are due to erosion, and these are of some interest. On the whole the summit is in many parts very rugged and diversified, with strongly marked features. The denudation of the Carboniferous has been exceedingly unequal in different places, and the portions of that series remaining are cut up into straggling masses, some of which preserve the Carboniferous system entire, and others preserve only the lower members. If we start from Agua Fria and move northwestward along the edge of the granite we shall observe on our left an escarpment of the edges of the Carboniferous strata. They dip strongly to the southwest and expose towards us only their outcrops. On the other side of their crest-line is the broad, sloping flank of the plateau descending into the plains beyond. On the nearer side the basal members of the Lower Aubrey reach out towards us a mile or two, until finally cut off by erosion at the granitic border. This escarpment extends without material interruption for 50 miles to the northwestward, forming one side of a broad valley which is nearly coextensive with the length of the entire summit and parallel to its axis. The other side of the valley is variously formed in different parts of its length. It is formed by the slopes of the granitic area, which, at first slowly and afterward more rapidly, ascend towards the boss of Mount Sedgwick. After passing the western angle of the largest granitic area we find on the right a counter-escarpment of the Carboniferous cliffs which presents the whole Aubrey series, thus mating the escarpment on the left. If we ascend the northeastern wall we shall find the surface above composed of the adamantine sandstone before referred to. The platform is deeply scored with true cañons, and so much cut up by them that travel is somewhat difficult. In the longitudinal broad valley between the two main lines of escarpment erosion has penetrated again quite through the Carboniferous series and exposed a second small area of the granite.

Still further northwestward we find the country much cut up and in an irregular manner by the inequalities of erosion, so much so that all attempts to describe it in detail seem futile.

In the study of geological subjects in the Plateau country the relations of the drainage channels to the topography and structure have always been regarded as important and instructive. We find the fact everywhere exemplified that the principal drainage channels are of great antiquity, and whatever may have been the changes which a locality or region may have undergone, the larger water-courses have preserved their positions. They are the least changeful of all the topographic features. By reason of their stubborn persistence they become instructive; for they indicate former relations to the slopes of the country which have been profoundly changed since the time when they began to carry away the drainage, and of which no other traces now remain. It was to be expected that some information of this kind might be derived from the study of the waterways of the Zuñi Plateau. In this I have been in a great measure disappointed. The reason, however, soon became obvious. The plateau is situated upon the line of the Continental divide. It never had any large streams, for it lies where, from the nature of the case, all streams must make their smallest beginnings; and the divide has probably undergone very few and slight changes since its first establishment, far back in Tertiary time.

Still there are points of minor interest in this connection which may be adverted to. If we note the position of the axis of the plateau on the portion which lies east of the continental divide we shall find that the waterways run obliquely across it. The streams head on the verge of the southwestern flank and flow eastward across the summit of the plateau, finding their way to the Bluewater and San José. The portion of the plateau summit which they cross is both structurally and topographically higher than the springs in which they rise. They find their way by means of eroded valleys. At the extreme western end of the largest granitic area a small stream takes its rise and flows a little north of east along the margin of the granite and enters the head of Bluewater Cañon. A few miles further to the southeast a second stream flows towards Zuñi Cañon, but it sinks long before reaching it. That it once sent its waters into that cañon becomes apparent when we examine it. Still further southeastward, at Agua Fria, is a third stream which flowing for seven or eight miles along the edge of the granite at length crosses it and enters the lava-covered valley south of Grant Station. All of these streams are very small; but there is reason to believe that a moister climate once prevailed in the Plateau country and that they were then larger and capable of continued corrasion of their channels.

CHAPTER IV.

MOUNT TAYLOR AND VICINITY.

Northeast of the Zuñi Plateau, and separated from it only by the valley of the San José, rises Mount Taylor. It is a large conical pile, planted upon a lofty mesa. It has no neighbors of its own kith and kin, though from its summit we can discern, many miles to the southward, several isolated mountains of inferior height and mass, which we know at once by their aspect to be volcanic. The platform on which it stands is composed wholly of Cretaceous strata and lava sheets. The latter form a capping or volcanic plateau and the thickness of this lava cap is seldom ess than 300 feet. Upon the surface it everywhere hides the sedimentary beds, but round the borders of the mesa and in the alcoves which are eroded into its margin the Cretaceous strata expose their edges and usually constitute from three-fifths to four-fifths the altitude of the bounding walls. The length of the Mount Taylor mesa is about 47 miles and its extreme breadth 23 miles. The broad plains surrounding this large mesa have a mean altitude of about 6,300 feet above the sea. They are somewhat higher upon the western side than upon the others, being there about 6,500 feet, while upon the east they are about 6,100 feet. The mean altitude of the summit of the mesa, exclusive of the cone of Mount Taylor, is about 8,200 feet, while the mountain peak itself attains 11,390 feet.

It will be seen that the volcanic cone occupies but a small portion of the area of the high platform on which it stands. It is merely the focus and culminating point of a rather large field of volcanic action. The mass of the cone itself is but a small fraction of the mass of lavas which form the capping of the mesa on which it stands. It is clear at once that these lavas in the volcanic cap did not all come from the main orifice, but that the greater part of them were disgorged from numberless vents scattered over its entire surface. Scores of these scattered vents are still discernible in every part of the plateau and always in a dilapidated condition. Here we have both the concentrated and the diffuse types of volcanic action in the same tract. From the summit of Mount Taylor, where we may overlook the entire mesa, we can discern many small mounds, which, upon closer inspection, prove to be small cinder-cones, and as we ramble over the surface of the mesa away from the mountain we find in the mazes of the forest the remnants of many more which could not be distinguished from the peak. There is not a recent one among them. All have been greatly wasted by long weathering, and the greater part of them are reduced to mere stumps or chaotic mounds. Most of the lapilli, which form the normal type of an andesitic cinder-cone, have been decomposed into soil and washed away, though usually some small remnants, and less frequently large remnants, still remain to attest their former characteristics.

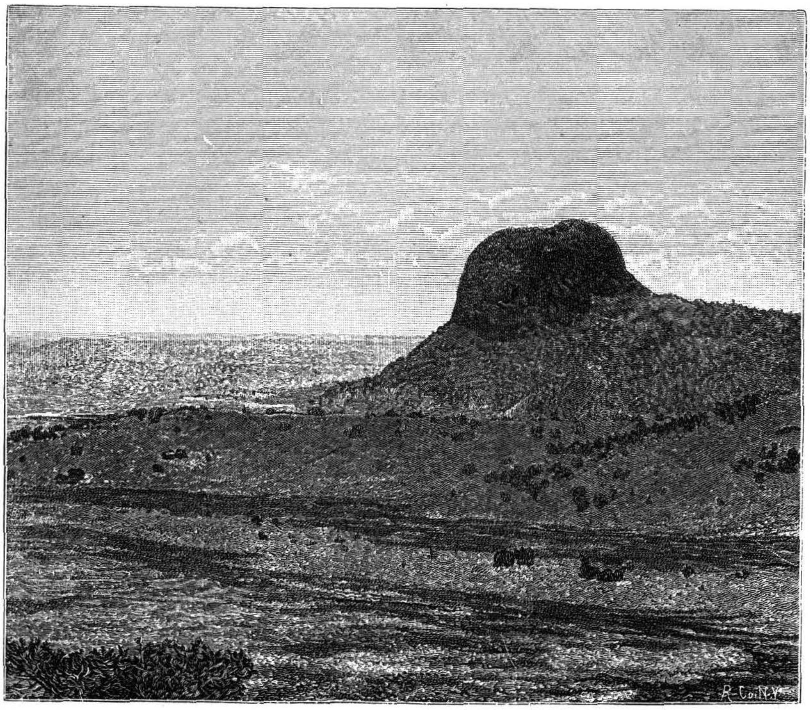


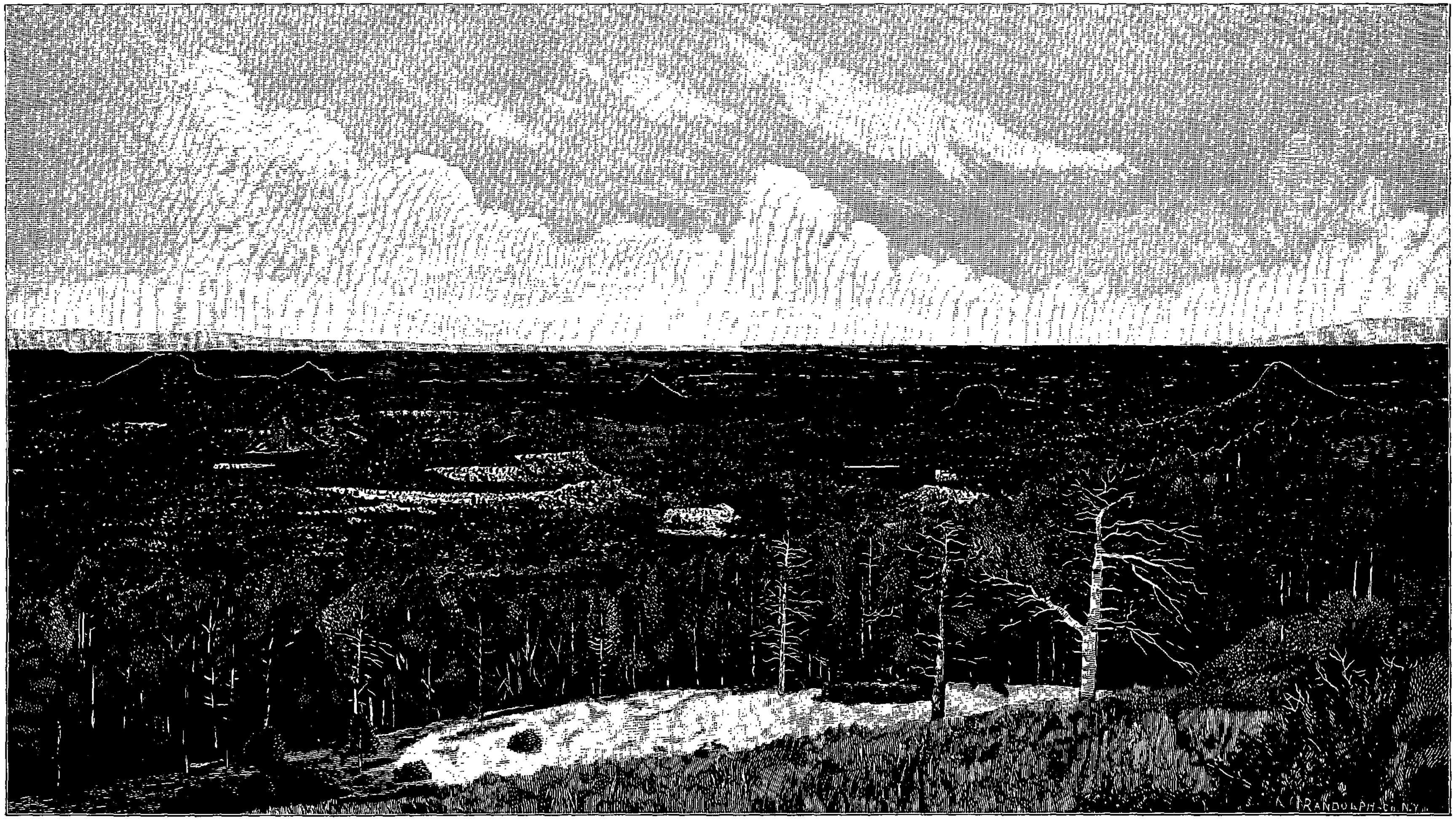
FIG. 17.—Neck near Juantafoya. Photographed on wood.

Of Mount Taylor itself there is little to be said, and the description may be very brief. Its structure and composition have nothing of novelty. It is a lava cone almost entirely, showing but few and insignificant traces of fragmental material, ejected from its central vent. Quite possibly or even probably such materials may once have formed a considerable portion of its upper cone, but if so they have long since been eroded away. Here and there, however, small masses of agglomerate may be seen included between lava sheets, and they are conspicuous rather for their rarity and comparatively small volume than for any other reason. There is but one pipe to the volcano and no traces of adnate orifices or cones are to be seen. This central pipe terminated in a large crater at the summit, the wall of which was broken down to the eastward in the later stages of the mountain's history. At the present time this old crater is much eroded, and it is now impossible to reconstruct in the imagination its original condition. Its general form, however, is apparent enough. It is very similar to the broken-down craters which are seen in many volcanic cones, such as Shasta and the San Francisco Mountain, in America, and the great Atrio of Vesuvius, or like the old craters of the Azores and the Canary Islands. Its amphitheatral form is still preserved in the main, but it has been much modified by the ravines which have been deeply incised by erosion. It is heavily timbered, and the rocks are mostly concealed by talus and soil as well as by vegetation. Nothing is revealed except what we are accustomed to see in all extinct craters which have been greatly battered by the elements. Many dikes are disclosed, many chaotic masses of lava, and some masses of breccia or agglomerate enveloped in the irregular tangled sheets of lava. The rock is mainly andesite, graduating in many places into basalt. No acidic rocks were discovered on the upper part of the mountain.

If the cone of Mount Taylor were all that this locality has to present for study it would hardly have repaid the trouble of a visit. But the volcanic district of which it is the culminating point presents matter of great interest and instruction when viewed as a whole, for it discloses clearly the origin of the great lava caps which form such a conspicuous feature in many parts of the West, and offers a wide range of information concerning the modes of accumulation of lavas in the basic group.

The great mesa on which Mount Taylor stands is one of a series, and it forms only a small part of a great volcanic field. To the southward lie the lofty mesas already spoken of as forming the continuation of the eastern belt of them, and these, too, are thickly sheeted over with andesite and basalt. Eastward of Mount Taylor and distant about 12 miles, is the Prieta mesa, which is also roofed over in the same way. But the most significant fact is the occurrence of plain evidences that the wide intervals which separate Mount Taylor from the Prieta on the one hand and the southern mesas on the other were once covered with a vast mass of Cretaceous strata, now eroded, and that these strata in turn were overflowed with lavas. Whether the volcanic sheets were of unbroken continuity across these intervals, or whether the denuded areas were only partially overflowed is now uncertain, but the fact is patent that a large expanse of volcanic rocks once covered areas from which they have been denuded, leaving, however, certain remarkable monuments of their former presence. These will now be described.

If we stand upon the eastern brink of the Mount Taylor mesa we shall overlook the broad valley of the Puerco (East). The spectacle is a fine one and in some respects extraordinary. The edge of the mesa suddenly descends by a succession of ledges and slopes nearly 2,000 feet into the rugged and highly diversified valley-plain below. The country beneath is a medley of low cliffs or bluffs, showing the light browns and pale yellows of the lower and middle Cretaceous sandstones and shales. Out of this confused patchwork of bright colors rise several objects of remarkable aspect. They are apparently inaccessible eyries of black rock, and at a rough guess, by comparison with the known



PANORAMA FROM THE EDGE OF THE MOUNT TAYLOR MESA.

altitudes of surrounding objects, their heights above the mean level of the adjoining plain may range from 800 to 1,500 feet. The blackness of their shade may be exaggerated by contrast with the brilliant colors of the rocks and soil out of which they rise, but their forms are even more striking. It is rare to find such shapes in the Plateau country, much more so elsewhere. It is obvious at once that these rocks are of volcanic origin; and the experienced geologist who has traveled much in these regions will recognize their significance at a glance, though their full meaning might not be at first apprehended by the layman. They are by no means unique, for Dr. Newberry has described some fine examples of the same type occurring in the valley of San Juan, far to the northwestward.

These black rocks are technically called "necks." Imagine the Cretaceous strata which have been denuded from this valley of the Puerco to be restored. We must replace in imagination fully 1,200 feet, and possibly much more, of the sandstones and shales in order to restore the sedimentary beds to the condition they were in when these necks were molten lava. Upwards through these strata the lavas found their way to the surface, where they outflowed; and no doubt cinder cones like

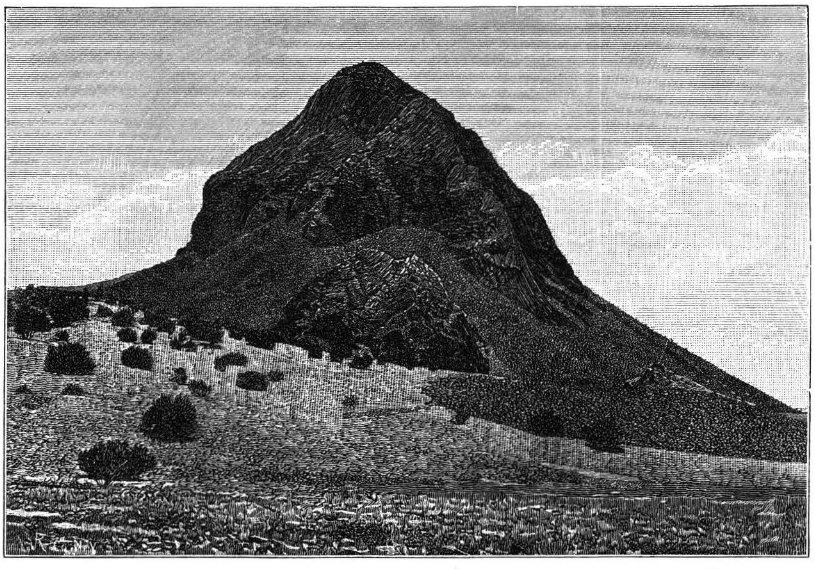


FIG. 18.—Neck five miles northeast of Juantafoya. Photographed on wood.

those which may still be seen by scores on the Mount Taylor mesa were formed over the orifices. When the eruptions ceased the lava remained solidified in the chimneys or passage-ways through which the streams had welled upwards. Then came a long period of erosion, in the course of which many hundreds of feet of Cretaceous strata and all the lava sheets and cinder cones which may have rested upon them were swept away from areas which aggregate thousands of square miles.

In the progress of this erosion the lavas which congealed in the pipes offered a much more obdurate resistance to the denuding agencies, and remain protruding upwards, while the beds which once inclosed them have vanished. The interpretation here given is such as would be accepted at once by any geologist, but the general reader might like some further proof of it. He can have an abundance.

When this scene (Plate XX) is first disclosed, as we come suddenly upon the brink of the mesa which overlooks it, the attention is chiefly engaged by about a dozen of these objects, which are especially striking on account of their great size, their singular forms, and their ominous black color. Soon, however, it is seen that there are many others which are smaller and less bold in outline and shade. There are still others which from this distance cannot be positively recognized as of identical character and origin, but may be suspected of being so; and the suspicion becomes in most cases a certainty when the localities are visited. Indeed, there are scores of these necks, and perhaps within an area of a thousand square miles, here well in view, there may be several hundreds of them. We begin to get positive proof of their origin when we make an examination of the steep slopes of the great mesa. Those which we first saw were miles away from it, and far out in the broad valley of the Puerco. But we soon perceive that they are even more numerous in close proximity to the mesa wall, and are frequently seen in the wall itself. The remoter ones have been completely exhumed and disengaged from the strata which once inclosed them, but those nearer the mesa still have large remnants of the inclosing strata around their bases and mounting high up. Nearer still, the amount and height of the inclosing beds increase, so that only the upper peaks of the necks protrude above them. In the wall of the mesa itself we find a number of cases in which a good section of the old volcano is given, disclosing not only the neck itself but the strata which included it, the lavas which flowed away from its orifice, and the cinder cone which was built on top of it. Fig. 24 is an instance of the latter kind. Thus nature has wonderfully dissected out for us the structure of these volcanoes and has dug away the earth from their roots. There is every gradation in the amount of exhumation and in the amount of destruction. Some are neatly cut in two, so as to expose their complete vertical sections, and these are revealed in the great wall of the mesa; others are just detached from the wall, and their cinder-cones are nearly gone; some are much shattered in their upper portions, and others are wasted to mere mounds. The smaller ones have, of course, suffered most, and they are (other things equal) the most obscured and most nearly obliterated. The farther away from the mesa the greater the amount of destruction, and at a distance of four or five miles from it only the largest ones are well preserved.

In order to appreciate what was the state of affairs when these vents were active, let us look at the mesa itself. Upon its broad summit the number of cones still identifiable probably exceeds a hundred and may exceed even two hundred. To count them was impossible, for it would have been necessary to traverse literally every square half mile. All of them are much ravaged by secular decay, and many of them are so far wasted that only a visit to their exact situations and a close view of the rocks in place can assure us of their reality. Even then extremely degraded vents may be incapable of identification. Many, however, can be pronounced upon with certainty miles away, and these appear to have been the larger ones and to have formed originally cones of mixed lava and lapilli of considerable magnitude. On the map one part near the center of the mesa is designated Sierra Chivoto. It is a cluster of large cones built of lava and cinder and much eroded. Two of them are between 800 and 1,000 feet in height and four or five others are only a little smaller. The distribution upon the mesa of those vents which are still identifiable is very irregular. In some places they are thickly clustered together, in others they are separated by intervals of three or four miles.

It is plain that the lava sheet which forms the capping of the mesa was gradually accumulated by the repeated outpourings of numberless local vents thus thickly scattered over its broad surface. And yet it may seem a little strange at first that this diffuse form of volcanic ac-

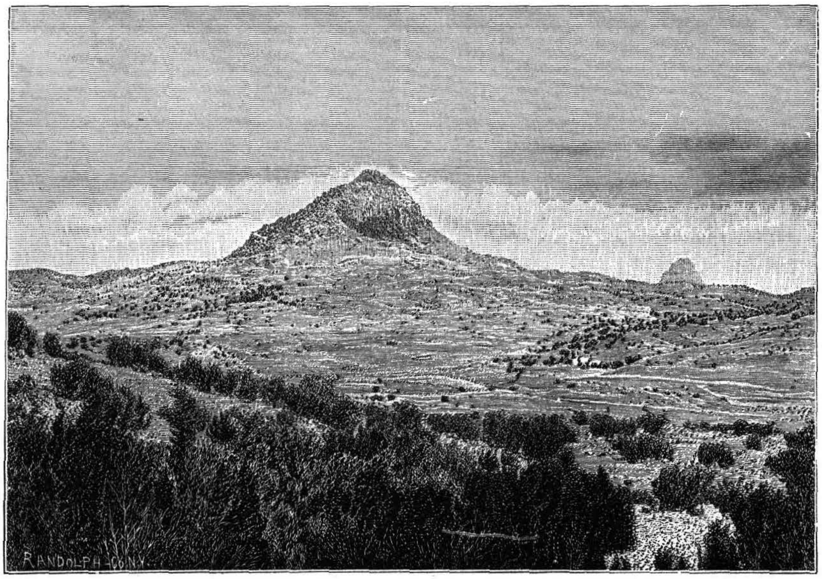


FIG. 19.—Neck six miles northeast of Juantafoya. Photographed on wood.

tion should have produced a surface which is so little diversified. Judging by the analogy of other regions, we should have expected to find the thickness of the lava cap extremely irregular and studded with large cones with intervening valleys of considerable depth. In reality the thickness as we recede from the base of Mount Taylor diminishes very slowly, and even at the extreme northern end is quite 300 feet. In truth, Mount Taylor does not appear to have contributed much, if any, to the lava which is more than five or six miles from the immediate base of its cone. The surface of the mesa away from the mountain is but little diversified, and the local cones are for the most part insignificant features. All this indicates a rather mild type of volcanic energy, in which the eruptions were not highly explosive but only moderately so. The more violent eruptions are attended with the ejection of great quantities of fragmental products, while the milder ones disgorge little else than flowing lava. It is well known, that the greater the amount of fragmental ejecta, the steeper and more compact is the cone or mountain built up around the vent, while the fluent lava spreads out over wide areas, often flowing great distances, and the slopes which it generates are much gentler and sometimes imperceptible to the unaided eye. As already remarked, fragmental ejecta are uncommon here, and I have seen none at all away from Mount Taylor except the lapilli in the cinder cones. We shall appreciate this mode of growth of a great lava cap when we come to study the modern lavas in the San José Valley, where their freshness enables us to see every detail of the process.

We may infer, then, that the state of affairs in the region now occupied by the valley of the Puerco was, during the activity of the vents

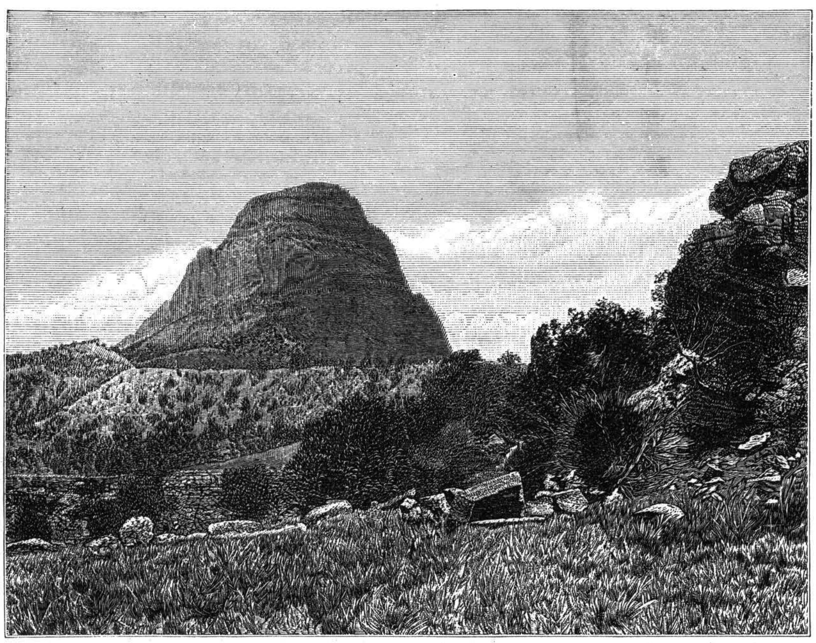
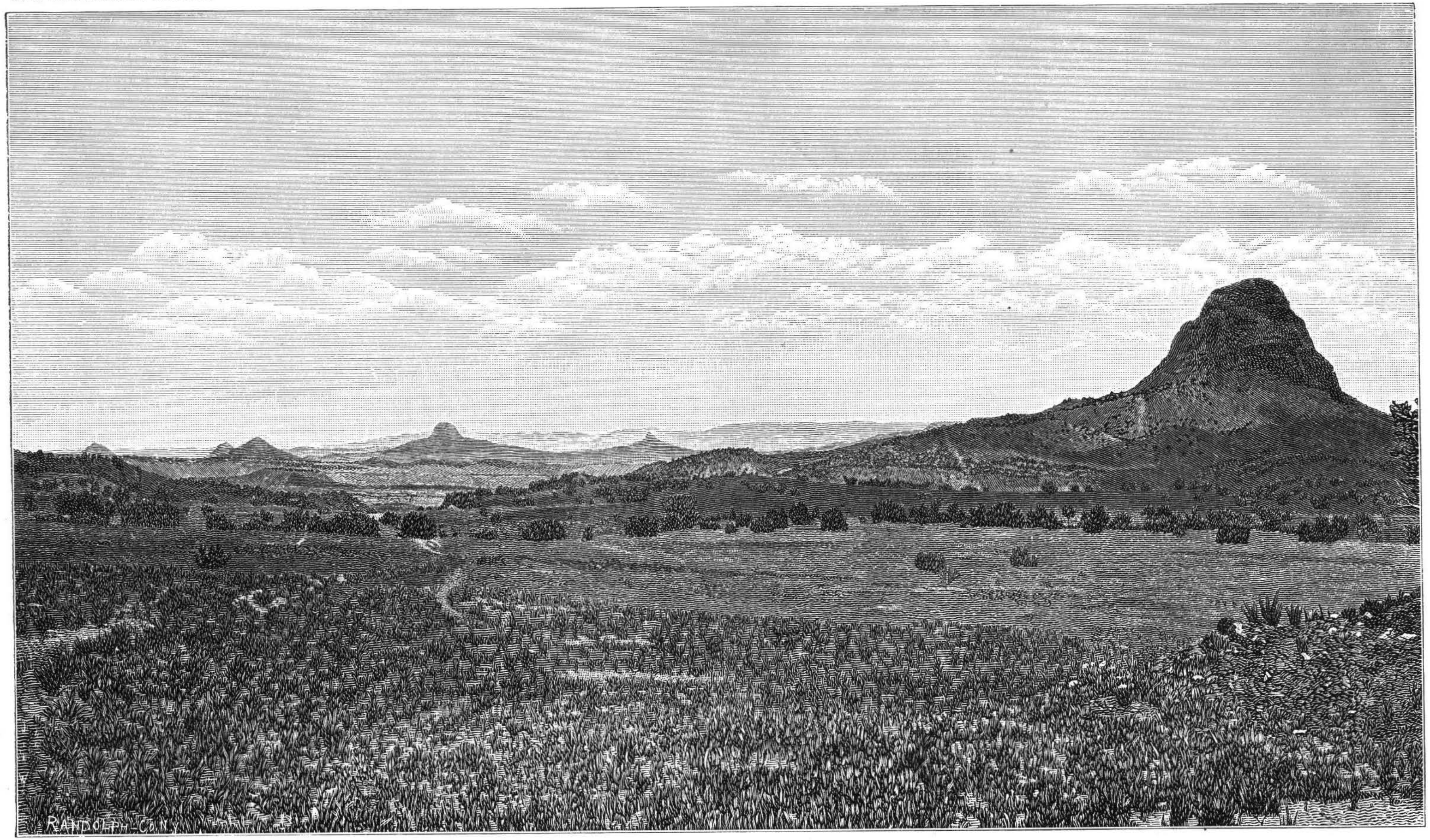


FIG. 20.—Great neck, eight miles south of Salazar. This is the finest one in the district with the exception of the Cabazon. Photographed on wood.

now represented by the necks, much the same as that which is indicated in the mesa above. From 1,000 to 1,500 feet (according to locality) of



PANORAMA IN THE VALLEY OF THE PUERCO.

Cretaceous strata, since eroded, then overspread the valley and regions to the eastward and southward, also to the northward, from which they have been swept away. Over their surfaces the lavas were outpoured from many vents. The eruptions were of a "mild" type, attended with little violence, and the ejecta were doubtless lava with few fragmental products. These streams, issuing from many vents, became interwoven with one another, and through a long period of time accumulated, sheet upon sheet, to great thickness, just as they have done in the valley of the San José in modern times. The result was a lava cap differing in no respect from that which is now seen upon the surviving mesas.

A fortnight's ramble over the mesa and another fortnight spent in the study of the necks in its vicinity will probably give a much clearer idea of how these great lava caps or "basaltic plateaus" were formed than can be gained in any other known locality. I am not aware that their origin has ever been explained so clearly as nature herself explains it here, though it has been inferred with tolerable accuracy in general terms by a few geologists. These inferences, however, have been largely theoretical and open to a great deal of debate by reason of assumptions which could not be satisfactorily verified by observation. This region is practically a demonstration. Many investigators in the field have attributed them to "massive eruptions," immense floods of lava pouring out of long, wide fissures, overwhelming great expanses of level country in a mighty deluge, without the formation of any marked cone or mountain. That massive eruptions of this sort have occurred is probable, and the valley of the Snake River, in Idaho, may be mentioned as the theater of some of them. But the sheets which so often cover the great mesas of the West are not of this origin. They are formed by the gradual piling up of sheet upon sheet of lavas poured from numberless vents scattered over their surfaces. The eruptions being of a comparatively mild type, the products are almost wholly liquid lavas, and great cones are not often formed. The lavas being highly liquid flow to great distances in thin streams, which are also very wide if the country is flat enough to permit them to spread out. Hence the ejecta, instead of piling up closely around the orifices, are widely dispersed, and accumulate with an approach to uniformity of thickness over the surrounding tracts.

Let us now examine some of the great necks standing in the Puerco Valley, and note such details as are visible. They are easily accessible from the railway, starting from the station at Laguna, or we may reach them from any direction with ease if we go horseback. Probably the most conspicuous ones lie between Juantafoya and the Cabazon. I had seen several of them, first in the vicinity of Cubero (or Covero), at the south end of the Mount Taylor mesa, but they were by no means the finest examples, though striking enough. Ascending the mesa, and wandering for a couple of days through its forests, I reached the brink of the lava cap above Juantafoya, where the impressive scene represented in Plate XX was suddenly disclosed to view. Descending the great mesa wall, and camping for the night near the little Mexican village, I began the examination of these necks the following morning. They were found to be very numerous. In dimensions, in the degrees of exposure, and in form they varied greatly. Photographs were made of the larger and most conspicuous ones, and some of these have been transferred to wood and engraved. These engravings will describe their forms and general appearance far better than words and it only remains to note some of the less obvious characters.

In all of these necks the basalt is columnar. The columns stand or lie in all sorts of attitudes, and in most cases are curved. Frequently they are grouped in radiating *fasciæ*, and at times are flexed and reflexed. The dimensions of the columns vary considerably. The smaller ones are not more than five or six inches in diameter, while in some necks they are more than twenty feet across. But when they are so large there is less regularity in every way, not only in the sizes of individual columns composing the same group, but the divisional planes between them are less smooth and precise. Where the columnar structure is so excessively coarse the columns are generally vertical. Nothing can exceed the beauty and symmetry of the smaller columns, and when they are flexed and reflexed they present a fanciful effect, which reminds us of the fibers of some huge organism. In nearly all of these necks, certainly in all of the larger ones, it is easy to see that numerous eruptions have occurred, for there are conspicuous divisional planes or surfaces of contact between streams which are certainly not contemporaneous. But the several masses are so contorted that it is impossible to determine any definite relations between them.

Upon the first general view of one of the larger necks the impression is gained that the horizontal section is nearly circular, but this impression is dispelled upon closer examination. In those parts which rise high above the surface the conjugate diameters are not far from equal. But this has been brought about by denudation. At the base of the exposed part the elongation in one direction is always noticeable and is sometimes great. The longer axis is frequently produced in both directions by dikes, which reach far away from the principal neck, but the dikes are broken down even with the general surface, and buried so that they do not appear except in close proximity to the main neck. Stellate (or star-shaped) cracks filled with lava are sometimes seen, but they are not common.

These ancient vents are no doubt situated upon local fissures which were rent open by the upward effort of the rising lava beneath. Probably the openings or gaps of these fissures never exceeded at first a few inches. Wherever the escape of steam was possible the vapors, under great tension, instantly rushed out and speedily enlarged a limited length of crack into a large roundish hole. The blast of steam escaping from a volcanic orifice has great force, even in eruptions of a mild type. In our mundane experience we can liken it to nothing but the explosion of such substances as gunpowder. To make the comparison more just we must imagine that intense action which takes place in a heavy cannon, but which is all over in a fraction of a second, to be kept

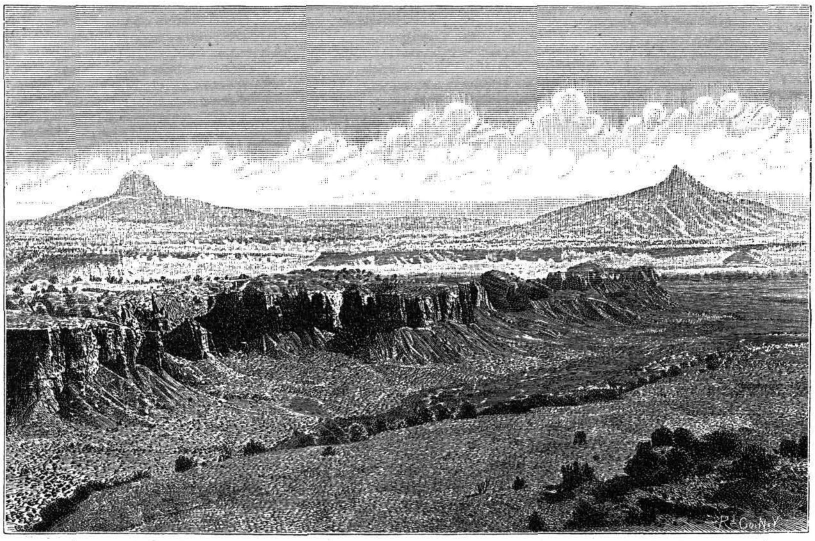


FIG. 21.—Two large necks, the more distant one being the Cabazon; Cretaceous mesas in the fore ground. Photographed on wood.

up with full intensity for hours and even days, or until the tension of the vapors is relaxed by their gradual exhaustion. Even this conception would fall short of the real intensity of the action in the case of eruptions of the more violent type.

The geologist will find it a most interesting journey from Juantafoya to Salazar and thence northward to the Cabazon. On the way he will pass a great number of large necks, rising to altitudes of many hundreds of feet and in one case to a height of very nearly 2,000 feet (Fig. 20). No names have been given to these objects, individually, and perhaps it is hardly profitable to attempt any other view of them than a collective one. As we leave the village of Juantafoya and move outward into the rugged valley of the Puerco we note several large and many small ones close at hand. Just south of the road is the neck represented in Fig. 17. Its shape is more regular than in most of them. The altitude above the inclosing sedimentary beds is about 650 feet and its diameter is about 900 feet. It rises 1,300 feet above the valley bottom. Its summit is inaccessible. In close proximity to it are several small necks, which are only partially disengaged from the sedimentary beds which inclose them. The large one is beautifully columnar and the columns are vertical.

North of the road are several large necks in the wall of the mesa itself. They are very much obscured, however, by the inclosing matrix of sedimentary strata, which mount up nearly to the summit, or to the base of the great lava cap, but are eroded away in a few places sufficiently to give glimpses of the neck within. Portions of the lava sheet and traces of the old cinder-cones which once stood above them are here preserved. The ceaseless sapping of time will ultimately bring them out by destroying the more perishable sedimentary beds and leave them standing, like their neighbors, isolated and conspicuous.

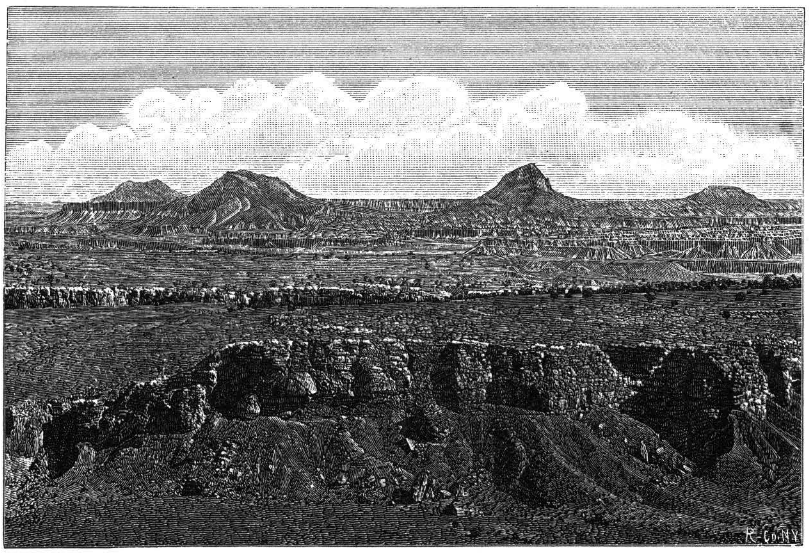
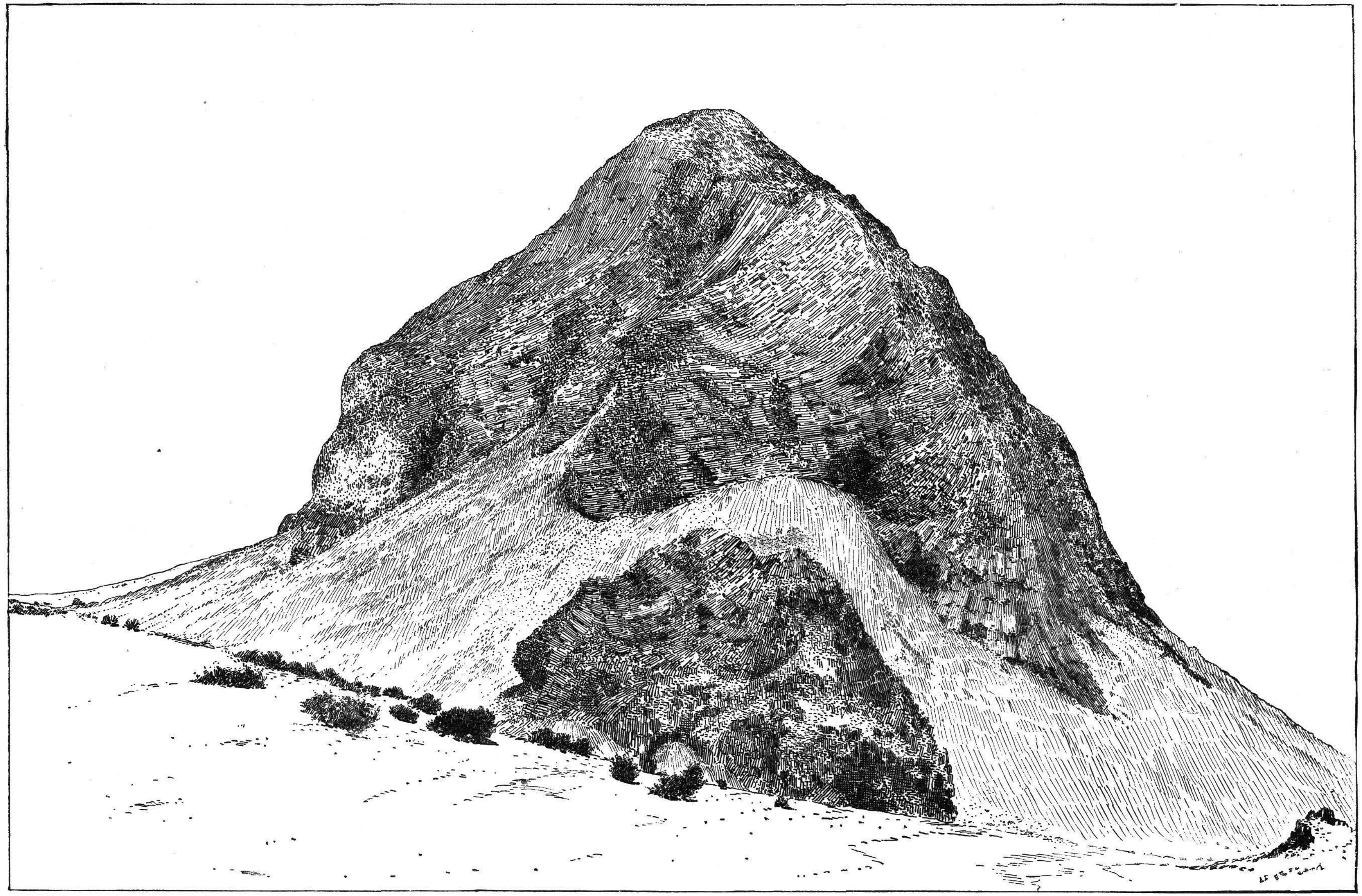


FIG. 22.—A group of necks among the Cretaceous beds north of the Mount Taylor mesa and southwest of the Cabazon. Photographed on wood.

Five or six miles from Juantafoya are two large necks with an interval of less than half a mile between them. One of them (Fig. 18) is noticeable on account of the intricate character of the columnar structure. Special pains have been taken to illustrate this by the drawing in Plate XXII.[1] This neck has a diameter of over 1,000 feet, and rises about 800 feet above the Cretaceous beds which inclose its base and 1,400 feet above the main valley.

About eight miles from Juantafoya we come upon the impressive scene represented in Plate XXI. On the right is the loftiest and finest neck in the region, with the exception of the Cabazon, which also appears in the middle of the picture, 17 miles away. Other large ones also are seen. The one on the right is also given in nearer view in Fig. 20. Its altitude above the valley is between 1,800 and 1,900 feet, but an intervening ridge of Cretaceous strata shuts off the lower portion from

[1] From the original negative an enlarged "positive" or transparency was made. From this a still larger negative was taken. With the enlarged negative a silver print on paper was then made, and over the print a pen-and-ink drawing was traced. The drawing was then bleached and the silver print dissolved out, leaving only the pen-work, which was reproduced on a greatly reduced scale by photo-engraving.



COLUMNAR STRUCTURE IN VOLCANIC NECK.

view. No opportunity occurred to photograph it from a more eligible standpoint or even to visit it. At the distance of about a mile its intricate columnar structure was readily recognized with a field glass. Its diameter was estimated roughly at about 1,300 feet.

The largest neck in the region is the so-called Cabazon. It has been a famous landmark for many years, for it lies on the old road leading from Santa Fé to the southwestward, and over that road people have traveled for more than two hundred years. The view here given is from the southward, standing upon the lower benches of Cretaceous strata under the northern crest of the Mount Taylor mesa and six miles or more from the Cabazon. I was unable to visit it, much to my regret. But when the point from which this view was taken was reached, I had already been long away from my base of supplies and a tedious journey of nearly a hundred miles was necessary in order to reach it. This same neck is pictured by Dr. Newberry from the north side in his report of explorations from Santa Fé to the junction of the Grand and Green rivers. Within three or four miles of it are five other large necks, but they have been sadly wrecked by erosion and are in a ruinous condition. The topographers of the survey who have ascended the Cabazon find its summit to be 2,160 feet above the valley bottom. Its diameter is about 1,400 feet.

Much the greater portion of the necks is found in the valley of the Puerco. A considerable number, however, occur on the southern side of the Mount Taylor mesa, though few of them are of great dimensions in that quarter. On the western side of the mesa they are seen only in the mesa wall, or at short distances from it, while in the valley of the Puerco they are found far away. There they are as frequent in the midst of the wide interval as they are upon the immediate slopes of the mesa. The indications are that the original extension of the main lava cap and the field of volcanic activity was not much beyond its present western border. But towards the north and east it probably reached out very far, for we can hardly doubt that these necks all represent very voluminous outbursts of lava. That the lava cap of the Prieta mesa was once continuous with that around Mount Taylor seems highly probable from the great number of necks scattered over the intervening valley. Here the large necks are not only numerous, but for every large one there are many small ones which have been reduced to insignificant mounds, and which are seldom noticed until we are right upon them. Thus the great lava cap of the Mount Taylor mesa is but a small remnant of a far greater region once mantled over with andesite and basalt.

But let us look southward to the great belt of mesas which rise east of the Zuñi Plateau. These too are heavily lava capped, though enormously eroded. In all respects they are repetitions of the Mount Taylor mesa, except that no great volcanic cone rises from their broad summits. With a field glass one or two small hills may be discerned, which are presumed to be the fading remnants of cinder or lava cones, but they are insignificant features, hardly rippling the flatness of their summit profiles. They are separated from the Mount Taylor mesa by the valley of the San José (through which the railroad is laid), and this valley is apparently double, *i. e.*, a broad valley with a narrow and deeper one excavated in its wide bottom. It is very doubtful whether the lava caps of these southern mesas was continuous with that of Mount Taylor. I am inclined to think not, for no necks or dikes were noted south of the railroad. It is to be regretted that the map south of the atlas sheet accompanying this paper is not completed, for it contains these southern mesas and would show the relations of the two volcanic tracts. The southern margin of the completed sheet cuts off much that it is desirable to show both in the Zuñi Plateau and in the lava caps.

The story told by the volcanic necks is in its final summary the same one that is revealed by every feature of the Plateau country, viz, *ero-*

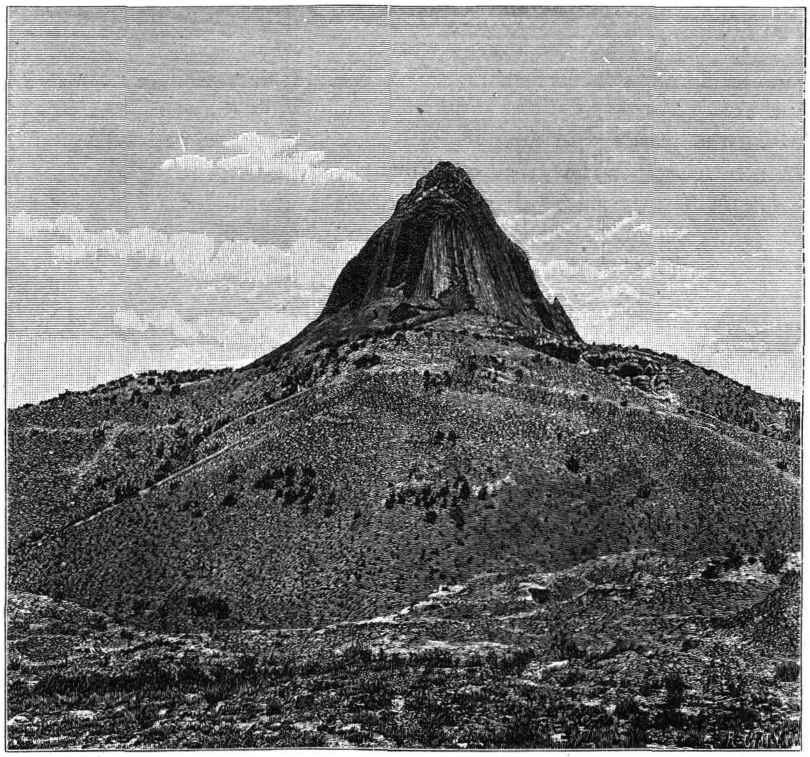


FIG. 23.—Alesna (the bodkin), on the northwestern side and near the base of the Mount Taylor mesa. It is beautifully columnar. Photographed on wood.

sion. Had there been no lava caps and no such necks we should never have hesitated for a moment in the conclusion that thousands of feet of strata have been eroded from thousands of square miles of territory.

The horizontal beds of Cretaceous strata, with their edges cut off abruptly in the mesa walls, and staring across a valley, be it wide or narrow, to the edges of the same beds on the other side, can only mean one thing in the Plateau country. If further proof were wanted, it is found abundantly in the lower Cretaceous strata in the valley bottom, untroubled by fault or fold; in numberless remnants of higher beds, forming the rolling hills and lying in their normal places and horizons; in the absence of any reason whatever for breaking the original continuity of a system of strata which is coextensive with half of the continent. The geologist in the Plateau country no longer winces at statements of stupendous erosion, for the vastness of its achievements is forced home to him at every changing prospect, with proofs so clear and palpable that even the wretched Indians see them and appreciate them. But however well a general fact may be known, however firmly a natural law may be established, it is always pleasing to come across some new demonstration of it. The kind of testimony proving a great erosion which we find in these lofty necks is so far as I know unique. And how could testimony be more conclusive? True, it adds no further certainty to that which was absolutely certain before, but it does add to our confidence in the methods and generalizations which we employ in the solution of great problems in physical geology and it gives us enlarged views of the "harmonies of nature."

What was the age of these eruptions? They were Tertiary; probably Middle Tertiary. They prevailed doubtless through a long period of geographical time. None of them can be regarded as recent in any sense whatever. Nowhere on the surface of Mount Taylor or of its surrounding lava sheet has any fresh-looking rock been found. The traces of time are visible everywhere. The mountain itself is deeply scarred with ravines, which have deepened into great gorges. The parasitic cones, which were numerous, have mostly been destroyed, and those which remain preserve only their most massive and enduring framework. The lapilli and clinkers have decayed into soil, and what were once large cinder-cones, inclosing craters, have become gently swelling mounds which only careful study can discriminate. Deep and wide barrancas or bays have been eroded into the mesa, and they are now inclosed by walls more than 1,000 feet high. The whole periphery of the mesa has greatly shrunken by the recession of its boundary wall through secular waste. The recession has no doubt been much greater in some places than in others, and it has been accomplished in the usual way, by cutting off and isolating buttes, which can be attacked on all sides. The erosion of the Puerco valley must, of course, have been accomplished since the extinction of the vents which were once open above the necks.

These eruptions, therefore, cannot be in any sense recent. On the other hand, there are reasons for believing that the earliest of them are not much, if any, older than the Miocene. They are as follows:

This portion of the Plateau province was very probably covered by the whole Cretaceous system of the West. It is quite possible that the lower Eocene also covered it—indeed, I had almost said probable—for the Eocene (Wasatch) beds occur in great force only a few miles to the north and northwest, with strong indications that they once extended far southward over regions from which they have been denuded. The Wasatch beds are, however, fresh-water formations, and though it is amazing what vast expanses of country they covered it seems incredible that they could have all formed a single lake bottom. What watershed could have been large enough in those times and in this region to keep such a lake fresh and brimming with water? On the whole there is much

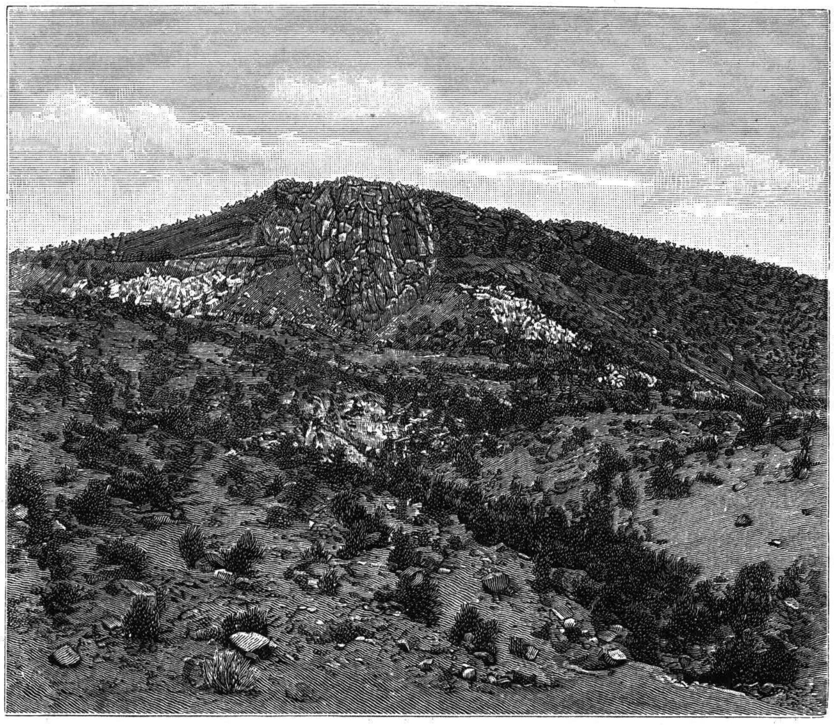


FIG. 24.—Cinder cone and neck, in a natural section in the mesa wall, seven miles northeast of Grant Station. The lighter-colored beds beneath the cone are Cretaceous sandstones. Photographed on wood.

reason to infer that these beds once covered the whole country hereabout, though the inference may be open to doubt. The lavas of this region do not rest upon these Eocene beds; they do not rest even upon the upper Cretaceous (Laramie) beds. Certainly the Laramie once covered the district, and it was eroded before the lavas broke forth; and its erosion could not have taken place until the general elevation of the Plateau country had begun and made progress. This we know to have been in late Eocene or early Miocene time, or, more probably, in both ages. These reasons have led me to incline to the early Miocene as the most probable age of the initial outbreaks. That they lasted through a long period is plain enough. As to the epoch at which they ceased, we can judge only by the amount of erosion they have undergone. This is very great, but any attempt to fix the epoch with precision would be going farther than the facts warrant.

RECENT LAVAS OF THE SAN JOSÉ VALLEY.

Travelers upon the Atlantic and Pacific Railroad seldom fail to observe the frequent fields of fresh lava which are seen soon after the train has passed the Rio Grande and begun its ascent to the westward. They occur in thin sheets, which have spread out over a country that has evidently been but little modified since their eruption. Some sheets are much fresher in appearance than others. Indeed, there are broad tracts where we have no hesitation in assigning a considerable age, and where the marks of erosion are very conspicuous. It is a country of low mesas, bounded by bluffs rather than cliffs, and some of these mesas, rising one or two hundred feet above the surrounding plains, show the eroded edges of lava caps. When we reach Laguna we find the valley nearly filled with young lava, the freshness of whose aspect is very striking. The interval between Laguna and McCarty's I have traversed twice by daylight in a railway car, but never otherwise; and, as I cannot assert the continuity of the lava between the two places, I have not represented it upon the map as so occurring. But I have ridden over the ground between McCarty's and Cubero, a few miles north of the railroad, where the country is flat and smooth, and I looked in vain for the source of this lava stream. I strongly suspect that this basalt came all the way down the San José valley from the same vents that furnished the broad expanses of young lava which lie to the southward and northwestward of Grant.

West of McCarty's there is no doubt. Streams of basalt fill the valley bottom and they are continuous with the main lava fields to the westward; their aspect is extremely fresh. Here and there some mud and alluvial sand have been washed over them, and the stream of water beneath has occasionally cut away the older river sands on which they lie, so as to undermine them. But the lava itself shows no erosion and no appreciable weathering. It is black and glassy, preserving its wrinkles, twisted knots, and clinkers in perfection. Its aspect is quite similar to the "pahoehoe" of the Hawaiian Islands, in those *coulées* which are less than a century old.

But the great display of recent lava is to be seen around the eastern base of the Zuñi Plateau. Just where the railroad emerges from the break through the mesas we enter upon a broad level plain, where basalts from two widely separated sources have intermingled. One of these sources is shown upon the colored geologic map about sixteen miles northwest of Grant or six miles north of Bluewater Station. The other source is a group of cinder-cones just beyond the southern limit of the map, about three miles southeast of Agua Fria. Imagine the red band which denotes the position of these basalt fields, and which is cut off at the southern border of the map, to extend about eight miles farther southward and then bend to the westward and farther on to the northwestward, thus forming a great hook. At the point of the hook near Agua Fria (but still off the map) are situated the vents which have given rise to this broad band of basalt. The lavas from the north of Bluewater meet those from Agua Fria on the plain between Grant and San Rafael. The vent from which the former streams flowed is designated on the map as the Tintero (inkstand), a low lava cone so inconspicuous that no geologist or other traveler who has written of this country appears to have noticed it hitherto. It has always been supposed that these fields of "malpais" emanated from Mount Taylor, and the supposition is a most natural one. Any one who crosses them or skirts along their edges without taking the pains to follow them to their sources would jump at once to that conclusion. From every point on the surface of the malpais Mount Taylor rises grandly as the most commanding object of the landscape; its volcanic nature is betrayed in every line and feature, and there is nothing else in sight to suggest a volcanic vent. But it is quite certain that they did not come from Mount Taylor, nor from any of its appanages; and the origin which I have stated has been verified with absolute certainty.

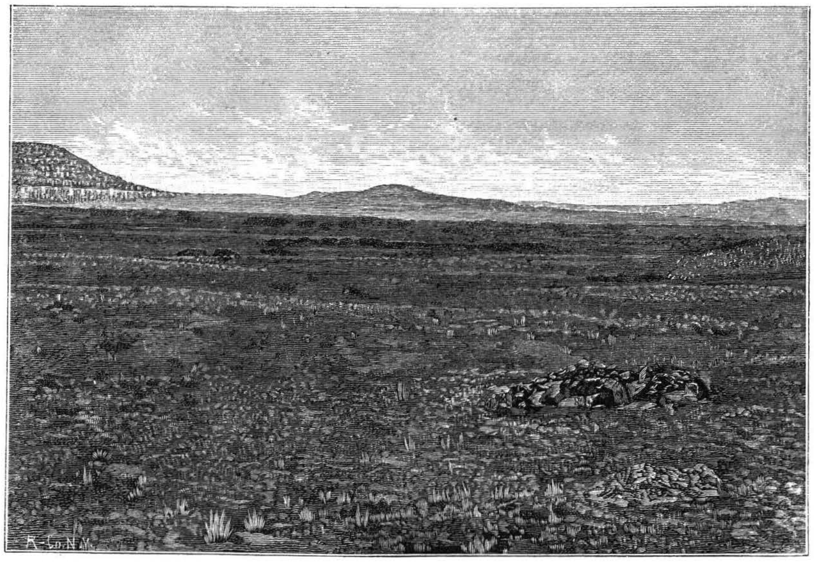


FIG. 25.—The Tintero, north of Bluewater. The cliff on the left in the background is the upper Jura-Trias. The Tintero is the small mound in the middle background; it is a lava cone and the source of the young lavas in the valley along the railroad between Grant and Bluewater. All of the flat space in the picture is basaltic lava. Photographed on wood.

The Tintero vent is a low mound, rising by feeble slopes to a height which is difficult to state for want of any definite plane to refer it to. It may be represented rather as the maximum point of thickness in the sheets of lava, which are piled one on another or which spread out from it in every direction except the north. A well developed crater is found at the summit. It is not composed of fragmental ejecta but of massive lavas. A distant view of it is given in Fig. 25. It is evident that many streams have flowed from it, spreading out east and west to a width of five miles and flowing southerly into the trough of the San José. Midway between Bluewater and Grant the streams narrow to the width of a mile or less. In many places the sheets are very fresh, but the older ones have been drifted over with blown sand and soil, through which the rough clinkers still project. Some of these streams may be many hundreds of years old, but others betoken such recency that we are tempted to attach some credence to the traditions of the Mexicans that when their Spanish ancestors first came to these regions they were still hot and steaming.

The coulées which came from the southward and from the sources near Agua Fria are more extensive than those from the Tintero. Their width in the valley between the slopes of the Zuñi Plateau and the Cretaceous mesas to the east is nearly four miles, and the distance from their sources to the railroad, where they commingle with those from the Tintero, is about 24 miles. There is no appreciable difference in the lithologic characters or in the outward aspects of the commingled sheets. Both of them are normal basalts, rich in olivine and augite, with triclinic feldspar. The Agua Fria vents have large and regular cinder-cones, and there is a group of four standing in close proximity to one another and rising from three to four hundred feet above the plain. The lava flows at first southeastward and gradually turns eastward and northward, crossing the granite axis of the Zuñi Plateau, which at this locality is greatly eroded and drops low, so as to give a gentle descent across it to the northward. It is difficult to judge what may be the thickness of the lava sheets, for there is no means of ascertaining what features had been given to the valley bottom by erosion before they were extravasated. Whatever it may have been, the floods of basalt have brought everything to a smooth surface, gently declining to the northward. The general impression conveyed is that the mean thickness is very small, not exceeding 100 feet, though in some places it may be considerably greater.

It may at first seem surprising to those who are unfamiliar with volcanic action that lavas can flow in such thin sheets to such great distances, especially when the declivity is so low as here, for the declivity is not more than 40 feet per mile. A visit to the volcanoes of the Hawaiian Islands afforded me an opportunity to study the details of the flow of lavas, and it has since then ceased to be at all perplexing. It may be well to describe the process here, especially as these lavas, lying along the course of a transcontinental railway, will be a source of interest and even wonder to thousands of future travelers.

It may be premised that these basalts clearly indicate that they were erupted without those manifestations of great violence and explosive energy which are so common in many other volcanic outbreaks. Their eruptions were of the "mild" type, not greatly exceeding in violence those of the Hawaiian volcanoes, which disgorge amazing quantities of fluent lava with so little disturbance that the vents may be approached on the windward sides as near as the radiant heat will permit. The ejecta in such eruptions consist of highly liquid lava alone. The quantity of lava is vast. It not only runs copiously but it runs a long time. In 1855–'56, Mauna Loa poured out a steady stream of great dimensions for thirteen months. In 1880–'81 its eruption lasted eleven months. The lava is highly liquid, and where the slope is great and the volume large it runs as swiftly as a flood of water. Over a flat plain, with a feeble declivity, the case is different; here the lava spreads out at once in a broad sheet and its surface is quickly cooled. But the crust which congeals is very thin and is the best possible non-conductor of heat. It becomes at once a most efficient protector of the lava beneath it from further loss of heat and consequent solidification. Beneath its protective covering the lava flows on, shooting out in advance of its front margin a succession of belches. Many lateral ruptures of the lava pipes also occur in the same way, and the stream both advances and widens. Its progress is slow over a feeble slope, and it may be many days or even weeks in advancing a single mile; but if the supply from the vent is copious and is maintained for a long time, the stream will continue to advance. It constructs its channels as it progresses, in which it is as thoroughly protected from freezing as the water in a river beneath its covering of ice.

In this manner the lavas of Mauna Loa flow more than forty miles. When they leave the vent they run into the tunnels which were formed by the earlier portions of the outflow, and do not come to the air again until the end of their journey is reached, 5, 10, 30, 40 miles away, as the case may be, and at the point where they break through the front of the stream they are about as hot and fluent as ever. Thus the length of the flow may be many miles. It all depends upon the copiousness of the supply from the vent and the length of time the supply is kept up.

We have in this region, therefore, eruptions of two distinct ages; those which built Mount Taylor and the lava caps of the mesas and those which flooded the valley of the San José. The former were probably of Middle Tertiary age (Miocene?), while the latter belong to modern times. Since the cessation of the former the country has undergone enormous changes by erosion and perhaps by displacement. Since the cessation of the latter it has undergone no material change whatever.

The study of the petrographic characters of the eruptive rocks of these localities has been begun and is in progress, but it has been found that more material is necessary. During the coming season I hope to have an opportunity to revisit the localities for the purpose of making larger collections and to publish the results of their examination. The study of them so far has proved to be of much interest, but any statements now would be premature.

CHAPTER V.

GENERAL CONCLUSIONS.

It now remains to inquire whether the facts observed in this field of study can be made to throw any light upon the evolution of the great region of which it forms a part. Of course it requires a great many facts and well connected observations to be able to generalize with any confidence, and it may be doubted whether we can at the present time do more than advert to some broad features in the most general way.

Of the history of the Plateau country prior to Carboniferous time we possess hardly any knowledge at all. Exposures of Pre-carboniferous strata are extremely few within the province itself, while around and near its margins they have been too little studied and are too complex and fragmentary to enable us to make even the first approximation to an idea of the state of affairs then prevailing. Within the province the very few exposures now known present the Carboniferous strata resting either upon the Cambrian or upon the Archean. The Devonian and Silurian are either wholly absent or are represented by a few eroded remnants of trifling extent. In the great natural section seen in the walls of the Grand Cañon of the Colorado we find the Red Wall group of the Carboniferous resting upon the upper Cambrian,[1] while

[1] In Monographs of the United States Geological Survey, Vol. II, Tertiary History of the Grand Cañon District, I described the appearance of this great section as seen from the brink of the wall above. At the time of my examination no fossils had been found below the Red Wall. From the cliffs above the most careful scrutiny fails to detect any unconformity in the stratification of the cañon wall except near the bottom of the chasm, where a hard quartzite is seen resting, with conspicuous unconformity, upon lower rocks. To the eye everything above this plane is indicative of complete parallelism in the strata throughout the hundreds of miles of exposure. So sharply are lines of stratification marked in the view of the wall that the slightest discordance should be apparent. Below the Red Wall limestones no fossils had been found up to the time of my visit, and these limestones have nearly 800 feet of sandy and shaly layers beneath them before the quartzite at the base of the conformable series is reached. It never occurred to me — it would have been almost incredible to anybody — that in the midst of this conformable series, exposed for 200 miles and more, there could be a great hiatus in the stratigraphic series, and though fossils were absent it seemed the most natural course to regard the whole as Carboniferous. A year or two after my departure, Mr. C. D. Walcott succeeded in reaching the depths of the cañon by a trail previously built for the purpose, and found an abundant fossil fauna of upper Cambrian age between the basal quartzite and the Red Wall limestones. In that conformable series, then, the Silurian and the Devonian are wanting. The fact is an amazing one, and so far as I know without a parallel. In the maps I have given with that monograph the Silurian is represented as being present beneath the Carboniferous. These supposed Silurian rocks are shown by Mr. Walcott to be Lower Cambrian, while the Upper Cambrian should take the place of the lower 600 or 700 feet, delineated as a part of the Lower Carboniferous or Red Wall group.

in the Zuñi Plateau and in the Nacimiento Range to the northeast the middle Carboniferous rests upon the Archean. We have merely facts enough to indicate that prior to the lower Carboniferous and Devonian ages some portions of the Plateau country were not submerged and received no deposits of sediment, but on the contrary were subject to denudation. The extent of these land areas—for such we may presume them to have been—we do not as yet know.

In the latter part of Carboniferous time the western portion of the United States was a marine area. This fact appears to have been coextensive with our knowledge of the geology. We may make whatever reservations prudence may demand concerning the parts which are unknown and the very few which are known imperfectly and are therefore doubtful. If any land existed there at that time it was of small extent. The strata are all marine deposits. As regards the Plateau country, it may be said that the Carboniferous strata disclose no land animals and no plants among their fossils, while the marine mollusca are as abundant as in any part of the world. They are indicative of waters which were neither very deep nor very shallow. The large quantity of limestone, the exceeding fineness of the sands composing the sandstones, and the calcareous cement which unites the grains are opposed to the inference that land was very near, but do not argue for great depths of water. There is, however, an absence of those positive signs of shallowness which are so abundant in the ages which followed.

Throughout the periods covering the deposition of the Permian and Jura-Trias formations we find a state of affairs indicated which it is difficult to explain satisfactorily. Mention has already been made of the remarkable constancy of the greater part of this series over the entire extent of the province. Its thickness is very great and its unbroken continuity over the whole cannot be questioned. Yet we find proofs that from time to time the sea deserted the country and left it to support for awhile an exuberant vegetation and a highly varied reptilian fauna, such as characterizes the lower Mesozoic wherever found. We have found hitherto very few marine mollusca. In the unquestioned Trias no marine shell has ever been discovered, so far as I know. The only ones yet found have come from near the base of the Permian and from the upper Jurassic (?). They are just enough to assure us that the sea at times covered the province. Curiously enough Professor Cope has discovered in the Trias of New Mexico a few shells which Meek regards as Unionidæ. Shells of the same family have also been discovered in the Jurassic at other localities. Dr. White is of the opinion that it is a reasonable question whether the representatives of this family found in the early Mesozoic may not have lived in salt water, though their modern derivatives are fresh-water species.

But while these strata are so extremely poor in the remains of marine animals they are rich almost beyond comparison in the remnants of vegetation. The abundance of fossil wood has already been spoken of.

It occurs at many horizons, but is most abundant in the upper Permian and lower Trias. Great quantities are also found in the Jurassic; but wherever the country is surfaced with lower Triassic strata the soil is full of fragments of silicified wood, and at some horizons the decay of the shaly beds discloses thousands upon thousands of fallen trunks, often of great size, slowly weathering out of the rock which inclosed them.

A common occurrence in this series of strata is unconformity by erosion only and without any perceptible discrepancy of dip, as if the country had been exposed for a short time to a feeble erosive action and then submerged again to receive another deposit of strata. These peculiar unconformities occur at numerous horizons and are usually hard to detect. But the many and very extended exposures often reveal it. In truth the whole tenor of the evidence accords well with the inference that the surface of the Plateau country during Mesozoic time coincided very nearly with sea level, but was continually oscillating from a little above to a little below that level and *vice versa.* At one time it was a land area, sustaining a great forest vegetation, through which many species of dinosaurs wandered; at another it was overflowed by the ocean, and received deposits of fine sand, clay, and salts of lime. On the whole the region appears to have subsided about as fast as the sediments accumulated, thus preserving the surface nearly at a constant level. We are tempted here to surmise that these oscillations between land and water may have been due to variations in the absolute position of sea level, while the progressive subsidence was produced by the gross weight of the sediments themselves. Whatever may be the explanation, it is a most extraordinary fact that 3,000 to 4,000 feet of strata were accumulated upon an area of over 90,000 square miles and yet the surface of deposition was maintained throughout at approximately the same level or with very moderate variations from it.

Considerations very similar to the foregoing are presented by the Cretaceous system. Here we have an abundance of fossils of all kinds to guide us, and our conclusions may be drawn with more confidence. With the exception of the strata forming the Laramie or uppermost group of the Cretaceous, the Molluscan fossils are of marine types. In the Laramie they are brackish water forms. As in the Jura-Trias, there were alternations of land and sea, and whenever the sea withdrew the land thus laid bare bloomed with forests and swarmed with dinosaurs. Here we find for the first time in the West conditions favorable for the formation of coal. From top to bottom the shaly beds of the Cretaceous include coal seams and carbonaceous layers, while the intervening beds abound in fossil leaves. The Carboniferous age of the Appalachians repeated itself here in the closing stages of the Mesozoic, and upon a scale of equal if not greater grandeur.

An interesting question arises here. How does it happen that coal did not form in the western Trias also? That vegetation was exuberant in that age is fully attested by the enormous abundance of fossil plants. The general mode of accumulation of the strata was apparently the same in both ages, and, so far as we can see, the topography and physical condition of the region remained unchanged. To the eye of the tourist who travels through the deserts of the Plateau country there is at first sight a total contrast between the aspects of the Upper and the Lower Mesozoic. By far the most striking difference is in the coloring. The Jura-Trias shows all the tints of the rainbow, drawing most heavily upon the reds. The Cretaceous merely rings the changes on neutral tints and lusterless browns. But how can mere color be associated with any determining factor in the problem? The sculptured forms of the two series also differ as much as the colors. This can be traced at once to the different modes of bedding. The Jura-Trias has many massive members of wonderfully homogeneous sandstone and softer beds of sandy shale. In the Cretaceous the massive members are in much less proportion and the shales in a much greater. But how can these differences be associated with causes which may lead to or prevent the formation of coal? As regards chemical constitution of the strata there are several important differences. The Jura-Trias abounds in sulphate of lime, sometimes taking the form of gypsum beds, sometimes of gypseous cement in the sandstones, and still more frequently of selenite in the sandy shales. It abounds also in the Cretaceous, but not to so great an extent. Clay shales and calcareous marls, with bands of limestone, are abundant in the Cretaceous and very scarce in the Jura-Trias. These differences might suggest to the ingenious speculator some considerations more to the point, but I see as yet no necessary connection with the inquiry. Certain it is that the Jura-Trias has never yielded in the West a trace of carbonaceous matter. Its trees and shrubs have turned into stone instead of coal.

We find as yet no evidence that the Plateau country was marked out or differentiated in any way from the country lying to the east of it, until the Laramie period. From the eastern border of the Great Basin province the whole Mesozoic system reaches eastward to the Missouri River. It is now interrupted in Colorado by the ranges of the Rocky system. But we are not in a position at present to form a confident opinion whether the mountain platforms from which it is now absent existed in Mesozoic time, or, if so, how far they were developed. The weight of opinion is in favor of the inference that some of them were already formed, and it is certain that some of them were not. A most interesting subject of future study will be the determination of the age and history of these ranges. Here also is opened up the question of the origin of the materials which constitute the Mesozoic strata of the West. Whence came they?

We know at present of one large Mesozoic land area which furnished a portion of them. It was the Great Basin; but its shore line has not been completely traced out as yet, though considerable portions of it are known. The eastern flank of the Wasatch, throughout the entire length of that chain, and the western boundary of the High Plateaus of Utah coincide closely with the location of a part of it. From the southeastern corner of Utah it is seen trending southwestward towards the southern end of the Sierra Nevada, but it has not been traced far in that direction. No doubt this land area was a large one, and we can fairly infer that it exceeded 200,000 square miles. Future discovery may prove that it was greatly elongated northward into British America. That it has been enormously ravaged by erosion throughout the whole of its known extent is abundantly proven, but it is hardly credible that this source could have furnished all the sediments of the Mesozoic strata, nor even the half of them, for they cover nearly a million and a half square miles, with an average thickness which may be estimated at not less than 3,500 feet and which may be considerably greater. To add a few islands in the sites of the Rocky ranges would help the matter but little. There is, however, reason to believe that some considerable land areas, most probably insular, existed at that time in Southern Arizona and Northern Mexico; but our knowledge on this point is far less complete than in the case of the Great Basin. Altogether, we are getting into sore straits to provide land areas sufficiently extensive to supply the materials constituting the western Mesozoic strata.

The fact is general that these strata grow thinner from west to east. Upon the southwestern border of the Great Basin the Trias has a thickness exceeding 5,000 feet. In the southern terraces of the High Plateaus it is rather less than 3,000 feet on an average, while in New Mexico (if we exclude the Zuñi sandstones) it is barely 2,000 feet. The Cretaceous is also somewhat thinner in New Mexico than in Utah, but the difference does not appear to be so great. Farther eastward, however, in Texas and near the Missouri River, the falling off in thickness becomes very marked. Still it is very remarkable how slowly this attenuation proceeds from west to east. Not only do these facts indicate a western origin for the sediments of the Mesozoic system, but they also indicate that they came from some source which was much more extensive than any island; in short, from some continental area, having a coast line many hundreds of miles long with numerous large rivers discharging sand and silt. While the amount derived from the Great Basin area was absolutely large, it seems more reasonable to regard it as merely an addition or reinforcement to still larger masses derived from a much greater and more prolific source.

In the Laramie period we discern the beginning of those movements which ultimately isolated the Plateau province and gave it its distinctive history and development. In this formation the fossils indicate the presence of brackish water, and this in turn indicates a restricted access of the sea by the elevation of partial land barriers around the borders. These Laramie formations covered a large portion of the west beside the Plateau country, and all of them present brackish-water fossils. They are found in Montana, Wyoming, Utah, Colorado, New Mexico, and even in old Mexico. Must we infer that there were many Baltics in that period? In truth the problem is not a little difficult, on account of the great extent and considerable mass of the Laramie strata. The great areas, however, are in many cases inferred rather than proven, and here we may be in danger of an overestimate. The Laramie beds, being high in the stratigraphic series, are greatly eroded, and even when the rest of the Cretaceous is present the remnants of the Laramie are much more restricted. We are seldom in doubt whether we can safely infer the former extension of the Lower and Middle Cretaceous over regions from which they are now absent. But with the Upper Cretaceous it is not so, and we are perhaps liable to error in applying to it the same reasoning. As regards the Plateau country, large remnants of the Laramie are found around its borders, *i. e.*, upon the northwestern, northern, and eastern margins. They are seen along more than half its perimeter. That they once covered the whole province seems the most natural inference, because it seems easier to conceive of one estuary than of many.

The passage from the Laramie period to the Eocene was marked by disturbances of which the traces are still visible. Around the borders of the Plateau province we find numerous unconformities between the Eocene and the Mesozoic strata. Near the close of the Cretaceous some of those great monoclinal flexures so characteristic of the region were formed, and the uplifted sides were eroded before the Eocene was deposited. The strata of the latter period are seen resting upon the beveled edges of flexed Cretaceous beds beneath. The fossils of the Eocene are brackish forms near the base, but these are replaced by fresh-water forms a little higher up. Thus we infer that the complete isolation of the Plateau province was accomplished at the beginning of Tertiary time, and its area became, in great part at least, a vast inland lake with an outlet. Whether its whole surface was thus overflowed is not yet certain. Within this lake large bodies of Eocene sediments were deposited. In the neighborhood of the Uintas their thickness attains fully 5,000 feet, and wherever we find the Eocene it is always a thick formation. In the Choiskai mesa, north of Fort Wingate, the sandstones referred to that age, and representing probably only the Wasatch group of it, are fully 1,200 feet in thickness. To the northward they are still heavier. It is noteworthy that the Plateau Eocene diminishes in volume from north to south and the characters of the strata indicate that the principal sources of its sediments were in that direction. This is intelligible. In the Eocene age the great mountain platforms of the Wasatch, Uintas, and Rockies had been upheaved and were undergoing a rapid denudation. The resulting sediments were in great part carried down into the lake. We do not as yet know of any other regions around its margin from which such masses of detritus might have come, though inferior portions may have been yielded by the Archean and Paleozoic ridges now lying southwest of the plateaus.

With the progress of Eocene time the lake of the Plateau region gradually vanished. The southern part seems to have been the first to dry up, while around the base of the Uintas its vanishing remnant lingered on until the Miocene. With the disappearance of its waters ended that long period of deposition, which reached from the beginning of the Carboniferous through the whole of that age and the Permian, through the whole Mesozoic, and through more or less of the Eocene. The results are certainly impressive. If we are at liberty to replace in imagination all the strata which have since been denuded we shall be led to the conclusion that over the entire surface strata had accumulated to a thickness of at least 15,000 feet in the western part of the province and at least 10,500 feet in the eastern part. At no time could the surface of deposition have been very far from sea level.

The progress of Tertiary time witnessed the slow elevation of the entire mountain and Plateau region of the West, and along with the elevation went the denudation of the country. The rate of denudation increases enormously with the altitude, and it has been so here. Recognizing the dependence of erosion upon elevatory movements, it is natural to seek among the detailed phenomena of the erosive processes some clew or hint leading to the various stages through which the region has approached its present structure and topography. The study of the Grand Cañon district led to some inferences of this kind, and to limited conclusions based upon the interrelated phenomena of structure, erosion, and volcanism. It was inferred that the western part of the province had been elevated, not at a uniform rate of vertical movement, but in periods of activity of the uplifting forces, with long intervening periods of rest. Whether this was true of the southeastern part of the province may not be so clear. Yet I think there are some indications of a rather recent and rapid elevation of great amount in the portion bordering upon the valley of the Rio Grande. In the Grand Cañon district reasons were given for inferring a great denudation in Middle Tertiary time, an age when the climate was moist, the elevation of the country considerable, and the rate of erosion very rapid. In the southeast we have also the conspicuous monuments of an erosion which, though much inferior in extent to that of the southwest, was still vast in amount. In that process the country was denuded of a large part of its Cretaceous and Eocene strata, and in some areas of a portion of its Jura-Trias. Since that erosion I believe that the district has risen greatly. My reasons for thinking so are as follows:

In the southeastern part of the province and east of the continental divide the valleys in which the tributaries of the Rio Grande flow are all very wide. There are no cañons within them, yet the declivities of those valleys are great—indeed, they are exceptionally great everywhere. Why have not cañons been cut in their floors? Because the climate is arid, the streams are either small or wholly wanting, and such as are still running are too feeble to carry their sediments.

They are choked with sand and mud, supplied by the Mesozoic rocks, which for the most part disintegrate readily. But if this climate were a moist one, and if the precipitation were copious, these slender threads of water would quickly swell to headlong torrents, the country would be quickly swept of its loose soil, and the beds of the streams would be laid bare to the scouring and grinding action of the rivers. In a very brief space of geologic time cañons as impressive as the tributary gorges of the Colorado would be scored in every valley. It might be difficult to render this clear to the general reader, or even to some geologists, without a long explanation. But to those who have fully studied the mechanism of rivers, especially those of the Plateau country, it needs no explanation. Now, when the climate of this country was moist, the rivers may have carried, and no doubt did carry, an abundance of water. But if the country was low and the declivities of their channels were very feeble no cañons would be cut, and the only possible action of erosion would be directed against the mesa walls and flanks of the more elevated masses. The rivers, in short, would be at or near their "base levels" of erosion, below which they could not cut. And this I conceive to have been the actual state of affairs. The late Eocene and Miocene were undoubtedly moist periods in this country. The rivers cut their channels down to base level, and erosion could do no more than plane down the adjoining country. During the Pliocene the climate became drier and finally as arid as it is to-day, if not more so. In that period I conceive the country was greatly upheaved. But the rivers had either disappeared or had shrunken to mere rills. In the Miocene the rivers had an abundance of water, but having already cut their channels down to base level they could not deepen them any farther for want of sufficient declivity. In the Pliocene the upheaval gave them a great declivity again, but they could not deepen their channels for want of water.

All this region proclaims an ancient erosion far more vigorous than the present. The wide, eroded valleys, fit for the passage of great rivers, but vacant now of flowing waters, their troughs half filled with alluvium, the grass growing over their broad flood plains, convey to my mind but this meaning. Hence I infer that the uplift which has given to these valleys so great a slope from the continental divide to the Rio Grande has occurred since that great erosion. And if we associate the principal erosion with a moist climate, as we seem compelled to do, we are impelled to refer it to the Miocene. Equally, if we associate the uplift with a dry climate, we can assign it only to the Pliocene. The amount of this elevation could not have been small. The average slope from the continental divide to the Rio Grande, while varying much according to the line we adopt, may average 3,100 or 3,200 feet in about 90 miles, or say 35 feet per mile. Under a moist climate a large stream would corrode its bed with one-tenth of that declivity. How much of this slope is due to the later upheaval we cannot estimate, though it seems probable that more than three-fourths of it should be so.

This inference correlates well with the conclusions drawn from the study of the Grand Cañon district. There, also, reasons were found, and of a more decided character, for inferring that a great uplift took place in the Pliocene. On the western side of the province, however, the uplifted platform was terminated along the lines of gigantic faults (Grand Wash and Hurricane), and the passage from the plateaus to the more confused structure of the Basin type is instantaneous. On the eastern side a long ramp leads down from the continental divide to the Rio Grande River, through a range of altitude which, as before stated, is a little over 3,000 feet. The length of this ramp varies from 75 to 90 miles.

The period during which the Zuñi Plateau was uplifted may be indicated with some degree of probability, though only within rather wide limits. In speaking of its uplifting we must be mindful of that more general movement which affected the whole region, as well as the more restricted movement which differentiates the plateau from the adjacent country. Its altitude may thus be regarded as the result of two independent movements superposed. Its differential uplifting doubtless goes far back in Tertiary time. It has erosional features peculiar to itself, consisting of true cañons of respectable depth, and these cañons are all of very ancient origin. They are the relics of the later stages of the presumed Miocene erosion, and had remained there throughout the long period of denudation which swept the whole Mesozoic series of strata from the summit and flanks of the plateau. But in order that they should be excavated at all, the declivities of the plateau must have been previously established. Hence I infer that the establishment of these declivities antedates the erosion, and may be referred to some period not later than the closing stages of the Eocene. They may be even older; but, on the other hand, they must be post Cretaceous, for the Cretaceous strata were involved in the flexures and monoclines produced by the hoisting of the plateau. This conclusion agrees well with the inferred age of numerous individual plateaus and mountain platforms in and around the province.

There is evidence that the eruptions which built up Mount Taylor and the volcanic caps of the mesas were subsequent to some part of the principal erosion of the country, though contemporaneous with a large part of it. In other words, they began after the denudation had made considerable progress. But the erosion continued in great force throughout the first volcanic period, and the eruptions slackened before the erosion did. These evidences have been recited in the preceding chapter.

The Zuñi Plateau is one of a class of structures characteristic of the Plateau country. No name has been given to them as a class, except the general ones "plateau" and "swell." In a former paper (Second Annual Report of the United States Geological Survey, 1880-'81, page 56) I have described a similar structure in the northern part of the province, lying about 70 to 100 miles south of the Uinta Mountains. It has been named by the geologists of this survey the San Rafael Swell. It is an uplift of considerable magnitude, comparable to a short mountain range in extent. It is greatly eroded, having been stripped of nearly 8,000 feet, and perhaps much more, of Mesozoic and Tertiary strata; but nowhere is the Archean exposed, and even the surface of the Carboniferous is barely grazed where erosion has cut deepest. On the eastern side there is a monocline of grand proportions, rapidly dropping the strata to the eastward and flexing them at a high angle. The similarity between the structure of the San Rafael Swell and that of the Zuñi Plateau is sufficiently striking. In the latter uplift, however, erosion has laid bare the Archean. We also see it exhibiting some added features. In several portions of its summit the metamorphic rocks have been protruded upwards higher than in others. In one tract especially, Mount Sedgwick, these rocks now overtop the highest remnants of Carboniferous strata, and in rising they have involved and metamorphosed portions of the sandstones which lay at the base of the Carboniferous and reposed originally upon the eroded surface of the granite. In others the upward protrusion is not so conspicuous, but is sufficiently pronounced to be of significance.

About 100 miles northeast of the Zuñi Plateau rises what is called the Nacimiento or Jemez range, which Dr. Newberry describes as follows:

Though not a lofty or extensive mountain range, this is perhaps the most instructive and interesting of all those which I had an opportunity of examining in the western country. Its extreme altitude is about 10,000 feet; its length something like 50 miles. Throughout this distance it forms a single simple ridge of nearly uniform height, with no peaks nor depressions. At either end it gradually falls off and is lost in the level of the Plateau country which nearly surrounds it. Although its physical features are so unpretending, its geologic structure is in the highest degree interesting and suggestive; such indeed that it seems to me it not only furnishes a key to the mode of formation of all the great ranges of the Rocky Mountain system to which it belongs, but that, if properly studied, it would serve to explain nearly all the difficulties of that now mooted subject, the origin of mountain chains. What its structure is may be very briefly told.

The central core or axis of the Nacimiento Mountain is composed of massive red granite, similar to that so common in the other ranges of the Rocky Mountain system. This forms its summit and the greater part of its mass. Upon the slope of the granite axis rests the Carboniferous formation, for the most part limestone, in many places nearly vertical, yet but slightly metamorphosed. Outside of the Carboniferous are the white and red sandstones, marls, and gypsums of the Trias; many of these beds also standing quite vertical, but wholly unchanged. Outside of the Trias the Lower Cretaceous rocks form another distinct circle; beyond these the Middle Cretaceous shales; still beyond, the great group of Upper Cretaceous sandstones and marls which I have just described. When we stood on the summit of the mountain all these different formations were spread out before us as on a geological map, each distinguishable by its color or texture, and as readily recognized as though traced on a diagram for a lecture-room. * * * Some five miles north of our position the range falls off and disappears in the plain, but the line of upheaval is distinctly marked by an arching of the unbroken sedimentary rocks. The upper part of the arch is removed, and the surface rock is a pure white sandstone, probably Triassic, beneath which the 'red beds' appear, forming on the east side of the mountain a beautiful rose-red valley.[1]

Dr. Newberry's description of the Nacimiento Mountain (?) is an exceedingly close characterization of the Zuñi Plateau. The difference between the two uplifts must be slight, and yet there appears to be a difference. The tenor of his description suggests a mountain platform in a more advanced stage of development, and just such an one as the Zuñi Plateau would have become if the orogenic forces and the correlative denuding agencies had proceeded a little farther in their action.

North of the Nacimiento we find the beginnings of the great Rocky ranges. East of the Rio Grande rises one of the grandest of them, the Sangre de Cristo, and west of the river is the San Juan range. The former is a granitic core, flanked on its eastern side by the Carboniferous and Mesozoic strata turned up in a great monocline. West of it is the great San Luis Valley, where none of those strata are seen, for it is flooded with vast sheets of basalt or mantled with more recent alluvia. In the San Juan range is a dreary expanse of eruptive rocks of many kinds and enormous accumulations of volcanic conglomerate, out of which rise isolated bosses of granite and quartzite. Not until we reach the western flank of this range do the sedimentaries reappear. In Dr. Hayden's atlas the sections through these two mountain platforms show no sedimentary strata between the eastern flank of the Sangre de Cristo and the western flank of the San Juan range, with the exception of recent alluvia. A portion of the core of the former range is described as consisting of "eruptive granite," a term which I have no doubt truly characterizes its structure and genesis. Upon both ranges are found numerous bosses of granite, which have been protruded upwards higher than the main granitic platform of which they are parts. Here we may recognize a still more advanced stage of the action of the orogenic forces.

Proceeding farther northward, in the heart of the great Rocky ranges, the Front, the Snowy or Park range, the Sawatch, we find a structure of homologous character, but somewhat obscured by other features. In the Nacimiento, the Sangre de Cristo, and the San Juan Mountains we find no unaltered sedimentary beds except on their outermost flanks. Once we have passed their upturned edges we see no more of them. In the mountain platforms of Colorado we find that the rising bosses of granite have not only flexed up the beds on the sides of the ranges but have caught remnants of them within their "disturbed tracts" and carried them up with them, bending, warping, and twisting them, shattering and faulting them. In the valleys between the great ridges large

[1] Exploring Expedition from Sante Fé, New Mexico, to the Junction of the Grand and Green Rivers, 1859, by Capt. J. N. Macomb, with geological report by J. S. Newberry. Washington, D. C., 1876, page 114.

tracts of Paleozoic and Mesozoic strata have occasionally been preserved but they generally occupy relatively depressed positions, and all around their margins their edges are either turned up on the flanks of the mountains which environ them on all sides or are abruptly faulted. Never do we find in the mountains of Colorado any of that extreme and close plication which is seen in the Alps. The most extreme case hitherto described is that of the Elk Mountains, so well delineated by Mr. Holmes.[1] Here the Cretaceous upon the western flank of the range is turned upside down, its edge folded completely over upon itself, and the fold apparently thrust in under the base of the mountain. The rock constituting the mass of the mountain is the so called eruptive[2] granite, and it has apparently flowed upwards and spread out laterally over the fold as if it had once been in a pasty or highly viscous condition.

In the Wasatch we find still another modification of this action. Here the sedimentary series is very much thicker than in Colorado, and includes great masses of the Silurian and Cambrian. The total thickness is about four times as great as in the Park ranges. Still the granitic bosses have, in many of the peaks, protruded completely through the entire sedimentary series, erosion keeping pace with the upward movement of the granite, while the Paleozoic strata have been turned up at high angles and in some places stand quite vertical. A great amount of faulting and minor complication has accompanied the movement. The rising bosses throughout this range have shown a tendency to seek the western side of the mountains as an avenue of escape, and have produced on that side an abrupt fault, if such it may be called. In truth, it seems better here to lay aside the conception of a fault, and conceive of the strata as having been rent asunder along a general north and south line, and the strata east of the break rolled over to the eastward and to a considerable extent backwards from the north and south flanks of the individual bosses. In many parts of the range the granite has not reached the surface, but the Paleozoic rocks form great monoclinal ridges, faulted upwards on the west and sloping at a high angle to the eastward.

The Wasatch is the type of the Basin ranges and the grandest of them all. The Great Basin is a region of Paleozoic and lower Mesozoic rocks accumulated in enormous masses and enormously eroded. Before

[1] Dr. Hayden's Annual Report for 1874, Eighth Annual Report of the United States Geological and Geographical Survey of the Territories.

[2] I have examined numerous specimens of this rock, and its true granitic character I think would not be questioned by any lithologist. As to its eruptive genesis, that is a question to be settled by field observation alone, and I place full confidence in the conclusions of those who have studied it. The evidence they adduce is to me ample. Nevertheless, there is room for inquiry as to the meaning of the word eruptive in this connection. That the granite has flowed up from the depths of the earth and spread out laterally seems unquestionable. But it may still be queried whether this flow was like that of lavas, occupying a few days or weeks, or was a slow, highly viscous movement, occupying a long period of time. The latter is to me the more probable view.

the present mountains were reared these strata had been greatly flexed and bent. The orogenic forces which have produced the existing mountains have operated in much the same way as in the Wasatch, but only in the greater ranges has the granite risen to the surface. The difference between the structures of the Great Basin and those of the Parks may perhaps arise from the fact that the granitic bosses which have pushed them up were much more deeply buried in the Basin area by rigid limestones and quartzites. The "disturbed tract" in each range is also narrower and shorter. Thus the Basin ranges are mostly shattered piles of sedimentary strata, pushed up by a resistless rising mass beneath, which sometimes reaches the surface, where it is laid bare by the denudation of the sedimentary rocks which originally covered it.

We have thus traced a series of mountain forms, from the extreme simplicity of structure disclosed in the Zuñi Plateau to the comparatively complex structure of the Wasatch and Basin ranges. But there is a generic idea running through them all. It is the idea that was taught us when we were school boys, that mountains consist of granitic or metamorphic cores, with sedimentary strata upturned upon their flanks. To this description the precisians have taken exception. They point to mountains which are composed throughout of sedimentary beds, and which disclose no trace of granite; to mountains composed wholly of crystalline rocks, with no unaltered strata in their vicinity. The objection seems to me to have no force. It may well be that in many cases the granitic core has not reached a sufficient height, and has not been sufficiently denuded, to be visible; but it is none the less there. Its action has been the same in kind, though it may have been less in degree, in those mountains where it is not disclosed, or it may have been of equal degree, but the granitic mass was originally so deeply buried that after rising a great distance the vast bodies of sediment still obscure it, as in the Basin ranges and in portions of the Wasatch. There is, however, a class of "mountains" which seem to have little or nothing in common with the structure here presented. Of this class the Appalachians and the Jura are the types. These systems of parallel ridges differ radically from anything found in the Rocky Mountain region, though upon the Pacific coast and in some parts of the Sierra Nevada something similar to them is found. The name mountains, when applied to such ranges, and also to the Rocky ranges, becomes, from a structural and genetic point of view, wholly misleading; and even from a topographic point of view the necessity for distinguishing names is apparent enough. In discussing the origin and development of mountains we should draw as wide a distinction between these two classes as we would between either one of them and a great volcanic pile. Nobody would think of attributing the building of a volcanic cone and of a range like the Wasatch to the same set of operations.[1] No more ought anybody to attrib-

[1] Yet I am fully convinced that the two categories of action have something in common.

ute the origin of the plicated *ridges* of Pennsylvania to the same kind of forces as those which produced the Park and Basin *ranges*. And yet this is just what many intelligent and able investigators of the problem of mountain building have been in the habit of doing. A volcanic pile is built by the accumulation of igneous ejecta. A mountain range, in the sense here used, is produced by subterranean forces acting vertically. A system of plicated ridges is apparently produced by the action of horizontal forces.

Within the past twelve or fifteen years it has become a widely accepted view among the geologists of Europe and America that the forces which have elevated mountains are derived from the strains set up in the outer envelopes of the earth by the secular cooling and shrinkage of its interior. But it should be borne in mind that geological science has flourished most in those countries where the best known and most thoroughly studied mountains and ridges are greatly plicated. To the European geologist the Alps and the Jura have always been the most commanding and interesting of orographic structures. To the Briton the highlands of Scotland and Wales have been equally absorbing fields of research in which the solution of the problem of mountain building has been attempted. In America geology had its first and most rapid growth in the Appalachian region, and when it sought fresh fields in the Pacific slope it first found them in the Coast Ranges and in the Sierra Nevada. All of these regions are more or less plicated, and it is not to be wondered at that an universal conviction should have grown up that plication and mountain building are only different names for one and the same thing, or that the process which built the mountains folded the strata at the same time. But as soon as the geologists penetrated the vast mountain belt which lies east of the Sierra and west of the Great Plains, and proceeded to a careful study of the forms there presented, a wholly different state of affairs was revealed. Not a trace of systematic plication has yet been found there. The terms "anticlinal" and "synclinal" have almost dropped out of the vocabulary of the Western geologist. The strata are often flexed, but the type of the flexure is the monocline.

Even in those portions of the West where anticlinal and synclinal flexures sometimes occur, as in the Basin ranges, we find that as a rule the mountain building and the flexing are wholly dissociated. The flexures belong to ancient disturbances, some of them Mesozoic others Paleozoic, while the hoisting of the ranges is much more recent, being mainly Middle and Late Tertiary. Even in the Sierra Nevada it is now coming to light that the intricate plications seen upon many portions of its flank were produced in Mesozoic time, while the principal uplifting of the existing range is Tertiary, and even late Tertiary. The Rocky Mountain region discloses whatever it has to tell us about physical geology with marvelous clearness and emphasis, but there is no teaching more clear or more emphatic than the absence of plicating forces from among the agencies which have built its magnificent ranges and hoisted its great plateaus. They have been lifted by vertical forces acting beneath them. The country at large shows no traces of a widespread, universal, horizontal compression; on the contrary, it discloses the absence of such stress. The only indications of horizontal force, and these are extremely few and local, are to be seen on the flanks of a very few ranges, where the plastic rising platform shows a disposition to *flow* away from the axis and roll backwards the flexed edges of the strata on its flanks. Here it is apparent that the horizontal force is a resultant of the upward movement of the plastic core and its tendency to flow away laterally. The more commonly accepted view of mountain building is the reverse of this, for it makes the upward movement a resultant of a resistless horizontal inward compression.

The absence of an universal state of horizontal compressive strain throughout the West, such as the contractional theory calls for, is manifested in many ways. It is seen in the dislocations of the Plateau country. Wherever a fault occurs, or a parallel group of them, the shearing of the strata is almost invariably clean and smooth. The mangling or tearing of the ruptured edges, the dragging of the beds, and mashing together are very rare and always local occurrences. The position of the fault plane is not often disclosed with certainty, but occasionally a cañon wall reveals it, and it is then seen to be either vertical or slightly inclined beneath the downthrow. In technical language, if it hades at all it hades to the downthrow; or, in miners' phraseology, the upthrow is the footwall, the downthrow is the hanging wall. In a plicated country, where horizontal strain has operated with great power, the dislocations are frequently reversed faults hading to the upthrow and usually accompanied with wrinkles or "troubles" at the fault planes and in certain rocks with slickensides. In some portions of the Plateau country we find what Powell terms zones of diverse displacement. They are situated (so far as known to me) in close proximity to the greater lines of dislocation, and consist of large blocks rifted with numerous faults and dropping below their natural positions, as if the general platform from which they have been rifted had undergone a certain amount of stretching instead of compression. Several of these are seen along the downthrow of the Hurricane fault in Arizona, and Gilbert has figured one occurring in the northern part of the high plateaus of Utah.[1] Throughout the vast regions surrounding the mountains we look in vain for any vestiges of horizontal compression. If it is so transcendent in amount as the theory implies, surely we ought to find traces of it in the hundreds of thousands of square miles of surrounding territory, where the strata are so wonderfully well exposed. But who has seen anything of the kind, and where are the traces of it to be found?

[1] Report on the Geology of the Henry Mountains, by G. K. Gilbert. It is also referred to in the Report on the Geology of the High Plateaus of Utah, and represented in the stereogram in the atlas accompanying the latter work.

But I have become too discursive. If an apology is needed it is because I am fond of viewing the facts observed in the field in their relations to broader and more general facts, and of marshaling them into their proper places. The Zuñi Plateau is not a feature which would at first impress any one with a profound sense of wonder or of admiration, but may appear rather insignificant when compared with the grander structures of the Rockies and other mountain systems. It is simple in the extreme; yet its very simplicity is full of significance. I look upon it as an embryonic mountain range, in which the orogenic forces have begun their work and display their modes of operation in the simplest and most intelligible manner. We seem here to get nearer to the real nature of the process which has built the mountains. Shorn of that extreme complexity which confuses and bewilders us in more highly developed structures, the great central facts and the true essence of the mechanical processes involved become much clearer. The mountains of the West have not been produced by horizontal compression, but by the action of some unknown forces beneath which have pushed them up.

PRELIMINARY PAPER

ON THE

DRIFTLESS AREA OF THE UPPER MISSISSIPPI VALLEY.

BY

T. C. CHAMBERLIN AND R. D. SALISBURY.

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Julius Bien & Co. Lith.

Scale 1 Inch = 150 Miles.

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THE DRIFTLESS AREA OF THE UPPER MISSISSIPPI.

By T. C. Chamberlin and R. D. Salisbury.

INTRODUCTION.

SIGNIFICANCE OF PHENOMENA.

In the midst of the great mantle of drift that overspreads the Upper Mississippi Basin there lies a drift-barren tract of about 10,000 square miles, the driftless area of Wisconsin and adjoining States. This island in the sea of drift is unique. To find that the crest of an eminence towered above the great mer de glace would not be remarkable; to find that the summit of a plateau near the border of the drift-covered area lifted itself above the invading ice would create no surprise; but to find a broad tract, lying in the very valley of the great river of the region, overlooked by higher land on different sides,[1] and yet untouched by the glaciation that prevailed all around, very naturally awakens marvel. Strangely enough, the margin of the drift on almost every hand lies on a slope descending toward the driftless district. The drift-bearing ice was stayed in its course, not by some acclivity, not by some great topographic barrier it could not overcome, but by some agency that arrested it in its downward career on the slopes toward the unglaciated basin.

The driftless character of the region has arrested the attention of geologists from the days of Owen to our own. The phenomenon has been noted and commented upon, and, like most great truths, has even been denied. Owen, Daniels, Percival, Whitney, Worthen, White, Murrish, Shaw, Winchell (N. H.), Irving, Strong, Dana, McGee, Squier, and the present writers have in turn made their contributions to the subject.[2]

[1] See Irving, Geology of Wisconsin, Vol. II, 1877, pp. 608–11.

[2] The following constitute all the publications relating specifically to the driftless character of this region which have fallen under our notice:

Dr. D. D. Owen. Geological Survey of Wisconsin, Iowa, and Illinois, 1839 and 1852.

Prof. Edward Daniels. Geological Report, 1853, p. 11.

Dr. James G. Percival. Annual Report of the Geological Survey of Wisconsin, 1855, pp. 29–31, 1856, pp. 17, 18.

Valuable as these have been, in varying degrees, the subject is yet a mine of truth largely unworked. The strange story it has been made to tell yields to the stranger story it must yet reveal when all its riddles are solved. We can easily foresee some of the lessons it must teach, though we are unable yet to fully read them.

As a non-glaciated area, standing in the midst of a vast tract overspread by drift for a distance of 340 miles to the west and south and for many hundreds of miles to the east and north, it becomes a standard of comparison and contrast between glaciated and unglaciated areas and a means of estimating the results of the drift agencies. It is the more valuable standard because the topographic conditions and the underlying formations are essentially the same; indeed, to a large extent they are specifically identical. The Mississippi Valley is glaciated above and below. The great river runs over the same formations in the drift region above and essentially the same in the drift region below. The Chippewa, Black, Wisconsin, and several lesser river valleys are glaciated in their upper stretches, but non-glaciated below. The crescentic Potsdam belt enters from a glaciated region on the east and passes out into a glaciated region on the west. The Lower Magnesian limestone does the same; so, also, do the St. Peter's sandstone, the Trenton and Galena limestones, the Hudson River shales, and the Niagara limestone. All of these, with their attendant topographies, carved into sinuous outlines by erosion, sweep curvingly across the driftless area from an ice-ridden region on the one hand to a like ice-ridden region on the other, displaying in a most striking manner the contrasts that arose

Prof. J. D. Whitney. Geology of Wisconsin, Vol. I, 1862, pp. 114–139; Geological Survey of Illinois, Vol. I, 1866, pp. 160–1.

Prof. A. H. Worthen. Geological Survey of Illinois, Vol. I, 1866, pp. 30–33.

Dr. C. A. White. Geology of Iowa, Vol. I, 1870, p. 87.

Mr. John Murrish. Report on the Geological Survey of the Lead Regions, 1871 (?), p. 14.

Mr. James Shaw. Geological Survey of Illinois, Vol. V, 1873, pp. 30–33.

Prof. N. H. Winchell. Geological and Natural History Survey of Minnesota. Fourth Annual Report, 1875, pp. 5, 21, 59–62. Fifth Annual Report, 1876, pp. 34–41. Vol. I, (final report), 1884, pp. 117–120, 213, 227–230, 245, 260–263, 275, 278, 311–313, 406.

Prof. R. D. Irving. Geology of Wisconsin, Vol. II, 1877, pp. 608–611, 632–634.

Mr. Moses Strong. Geology of Wisconsin, Vol. II, 1877, pp. 644–647; Vol. IV, 1882, pp. 92–94.

Prof. J. D. Dana. American Journal Science, April, 1878, p. 250.

Mr. W J McGee. On the Complete Series of Superficial Geological Formations in Northeastern Iowa. Proceedings of the American Association for the Advancement of Science, August, 1878. The Drainage System and the distribution of the loess of Eastern Iowa. Bulletin of the Philosophical Society of Washington, Vol. VI, 1883, pp. 93–97.

Prof. T. C. Chamberlin. Annual Report Wisconsin Geological Survey, 1878, pp. 21–32; Geology of Wisconsin, Vol. I, 1883, pp. 269–271.

Prof. R. D. Salisbury. Notes on the Driftless Area of Wisconsin. Transactions Wisconsin Academy of Sciences, Arts, and Letters, 1883.

Mr. G. H. Squier. Depth of the Glacial Submergence on the Upper Mississippi. Science, Vol. IV, 1884, p. 160.

from the single factor of glaciation. A unique opportunity for the comparison and contrast of drift-burdened and drift-free areas, of ice-worn, water-worn, and weather-etched surfaces, is thus happily afforded.

As a remnant of non-glacial erosion, the driftless area teaches us not only what drainage sculpture and weather-etching might have accomplished in the glaciated region, but approximately what they actually did accomplish. Here is a determinate and trustworthy standard from which to judge the character of the pre-glacial surface of the surrounding region. Similar standards are, to be sure, found in the unglaciated regions outside of the great drift field, and their value is not to be depreciated, but they lack some of the advantages of position here afforded.

In thus presenting us a type of non-glaciated topography, it furnishes a reliable basis for the estimation of the glacial planation which adjacent regions suffered. We are not left to arbitrary assumptions or to deductions from imagined processes. While in some instances certain variations from the standard offered in the driftless region need to be taken into account, yet, in the main, there is no reason to suppose that the Paleozoic tracts on either hand offered a topography essentially different from that which now prevails in this standard region.

But the topography of the drift region was not refashioned solely by glacial planation. A large factor—in the border regions probably a larger factor than planation—was the unequal distribution of the drift, which, in general, lodged in the valleys more freely than on the heights. The differences between adjoining glaciated and non-glaciated topographies are apparently due less to the glacial filing down of prominences than to the grading up of depressions. But whether the more was done by the one or by the other process—and the situation affords advantages for determining the ratio of these elements—the inequalities of the adjacent driftless region teach us, in a most convincing way, the amount of planation and of drift filling necessary to smooth up and grade down the inequalities and produce such relatively plane surfaces as the adjacent drift districts present.

In estimating the amount of drift in the glaciated regions, it is of supreme importance to know the inequalities of the rock-bottom. Our means of estimating the thickness of the drift are largely confined to wells and other artificial excavations; but our wells rarely penetrate below the common underground water-level, and this rarely lies much below the lower depressions of the drift surface. As these depressions are almost always less deep than the antecedent pre glacial valleys, the measurements afforded by wells rarely give the maximum depth of drift. Indeed, they rarely give us much more than the depths of drift upon what were the pre-glacial uplands or slopes. There lurks a serious error in current estimates of the depth of drift, arising from this fact. Some wells show the complete thickness of the drift because they reach rock, but a larger number have their base still in drift. To average all these and regard the result as an approximate estimate of the thickness of the drift, is manifestly an error because of the imperfection of a portion of the data. To equate only the depths of drift shown by the excavations which reach the rock and to ignore the rest, is scarcely less erroneous. Or still, again, to set aside the measurements of a portion of the wells that reach rock at shallow depths and to assume that a certain other class of greater depth fairly represents the thickness of the drift, is to predetermine the result sought in the assumptions made in the selection of the data. So far as we can see, therefore, there is no way of arriving at a satisfactory estimate of the average thickness of the drift, except by first determining the character of the rock bottom, into the inequalities of which the drift has insinuated itself.

There lies a strange paradox here. The *known* facts being what they are, viz, a given nature of the surface and a certain number of actual measurements of the thickness of the drift, then *the greater the glacial planation assumed, the less must be the estimate of the average thickness of the drift.* Or, conversely, *the less the glacial planation assumed, the greater the estimated amount of drift.* For the determined thicknesses of the drift, taking them as they run, mainly lie upon what were the pre-glacial ridges and uplands and show the thickness of the drift mantle at its thinner points presumably. Now, if the rock bottom is nearly plane, as would be true if we proceed on the presumption of extreme glacial planation, the average depths so measured would be nearly the average depth of the drift. But if, on the contrary, the underlying rock surface has not been glacially reduced and has great relief, as it has in the driftless region, a large allowance must be made for the drift absorbed by the deep valleys. Those, therefore, who assume that the ancient glaciers had little cutting power and produced

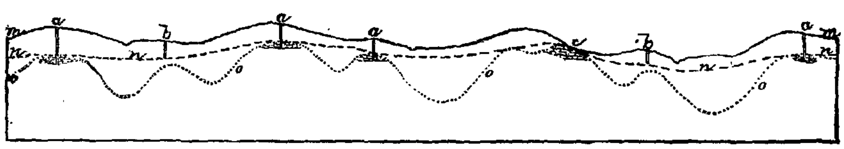


FIG. 26.— Profile illustrating the results of different assumptions in estimating the amount of drift.
a a a. Wells that reach rock.
b b b. Wells that do not reach rock.
c. Natural outcrop.
m m. Natural surface.
n n. Inferred rock surface under the hypothesis of severe glacial planation.
o o o. Inferred rock surface under the hypothesis of no glacial planation.

no essential effects on the rock surface must make a suitable allowance for the drift absorbed in the deep pre-glacial valleys. To illustrate: If the Great Lakes occupy essentially unmodified pre-glacial valleys, which had channel-ways leading out to the ocean and were attended by a complete system of tributary valleys, many of which must have been 1,000 feet deep to be in keeping with the primaries, the amount of drift must be large to block up these deep outlets and smooth off the surface to its present aspect. Those, on the other hand, who postulate extreme glacial erosion, by which the inequalities of the surface were cut away and broad, smooth basins excavated, must limit their estimates of the amount of drift somewhat closely to the average thickness shown by artificial excavations; for, under this hypothesis, the underlying floor is comparatively plane and there are few deep, capacious, drift-filled valleys to augment the estimate. In short, the known facts being what they are, a consistent estimate of the drift at any point, on the hypothesis of strong glacial abrasion, must be less than an equally consistent estimate on the hypothesis of little glacial abrasion. Pushed a little further, the paradox becomes more striking, and almost reduces itself to the absurdity: the greater the glacial abrasion, the smaller the drift material; the less the glacial abrasion, the more the drift. The lesson of the paradox is that both assumptions become irrational when pushed beyond a certain mean which is the truth. To ascertain this mean, resort must be had to a comparison between the actual contours which non-glaciated surfaces present and the actual contours which adjacent drift-covered regions afford. Upon the results of such comparisons, in the light of such data as may be derived from the study of drift thicknesses and the drift product, there may be based a rational estimate of the amount of reduction which the pre-glacial rock-surface suffered by glacial abrasion, and, supplementary to this, the amount of filling which took place in the leveling up of pre-glacial valleys by drift.

In view of these considerations, the contribution which the driftless region is competent to yield to the formation of a trustworthy estimate of the amount of drift and of the effects of glaciation becomes highly important.

But there is a still further element of vital consequence in the estimation of the quantity of true glacial drift and of the amount of glacial planation. It has sometimes been maintained that the drift is little more than the residuary earth and partially decomposed rock which overlay the surface at the time of the ice incursion, by which it was displaced, mixed, kneaded, and respread over the surface beyond. To determine the truth or falsity of this tenet, there are, among others, two prominent lines of investigation.

(1) A direct comparison may be made between the decomposition products and the glacial débris, to determine whether they are identical, whether the residuary earths and loosened rock, mixed and kneaded in any conceivable way, are competent to form the drift as we find it, independent of glacial grinding. In other words, we may ascertain by direct inspection whether the chemical constitution and physical condition of the residuary material are identical with those of the drift.

(2) In the pursuance of the second line, we may compare the quantities

of the two to ascertain whether the amount of residuary material is sufficient to fill the pre-glacial valleys and to level up the region into the existing drift plains that characterize the interior, making due allowances for the inequalities of redistribution. In the pursuance of either of these lines of investigation, the testimony of the driftless region is important. It affords an opportunity of determining the amount of decomposed surface material to be worked into drift, and, on the other hand, the capacity of the valleys which are to be filled. From these data we may estimate with some accuracy the effects that would be produced upon the topography if the residuary material were redistributed at pleasure in an endeavor to produce a surface like that of the drift country.

The driftless region is instructive concerning glacial extension and restriction; indeed, it is itself a peculiar expression of glacial limitation. It seems to us that its phenomena limit our permissible conceptions of the method of glacial extension to a certain range of views and debar us from others. The arrest of the ice while moving down the slopes towards the area—and that they were down slopes then, as now, can be proved—is only intelligible to us on the belief that these currents had entered an area of efficient wastage, and that their advance was antagonized by an ablation that consumed them before they reached the heart of the region. This is equivalent to saying that either the agencies of wastage springing from the driftless region were exceptional, for which we see no sufficient reason, or that the surface slope of the ice was moderate and its motion slow, which is probable; or that the zone of waste stretched far back on either hand and exposed a broad expanse of the ice to wastage, which we shall also maintain. We think there may be found, in a study of the zones of waste and of growth in the region about, and especially north of, the driftless area, phenomena which will check in the most profitable way our hypotheses of glacial growth, movement, and wastage and of the climatic conditions of glacial times. We may thus find assistance in confining our speculations to the neighborhood of truth.

The driftless region is exceedingly instructive concerning the glacial movements of a very large adjacent territory, and adds much strength to the evidence drawn from striation. The great drift-burdened ice stream, as it moved southwestward from the Canadian heights, was divided and diverted, and the separated currents swept around the area and mingled their burdens below it. Beside these leading phenomena, there are many strange features of a minor character which are displayed in the special movements of the marginal currents around the borders of the region.

In the study of these marginal phenomena the significant fact is developed that there are distinct varieties of drift border. Far from being alike on its several sides, the margin of the driftless region is, in one part, sharply limited by a stout moraine; in another part, it is bordered by a thin sheet of drift which has a definite limit but no marginal aggregation; while, in another part, the drift becomes attenuated to an extreme degree, and the point of its cessation is only determined by careful search for scattered and insignificant pebbles. Over a portion of the drift there is spread a mantle of loess, which stretches out upon the margin of the otherwise driftless region[1] and fades insensibly away. Over other portions, quite in contrast, no such mantle obtains. These varieties of drift border indicate corresponding differences in glacial and aqueous conditions, and these lead on to some of the most pregnant questions that spring from the drift of the interior.

Not only are there differences in the character of the drift border, but there were manifest differences in the drainage of the region at different stages. Over the western border, mantling its heights up to 700 feet and more above the Mississippi, lies the loess, for which we may find no other competent depositing agency than a fluvio-lacustrine one. At the same time we find, springing from the great moraine on the east and north, glacial flood deposits of gravel that sweep down through the valleys at heights varying from 50 to 100 feet above their present flood plains, i. e., 600 feet and more below the silt deposits. There are thus indicated drainage conditions of a strongly contrasted character. None of these conditions are identical with the existing ones, and in an endeavor to account for the changes we are led on to questions of crust oscillations, glacial dams, and other possible means of explanation of the anomalies which these extraordinary facts present.

So also there are differences in the relative antiquity or freshness of the drift deposits adjoining the driftless area, and thus we are introduced to the fertile question of glacial epochs.

Imperfect as is this sketch of the significances that spring from this unique region, it may be sufficient to indicate the pregnant character of the phenomena and the important place which they hold in the formation of rational conceptions of the history of the glacial period in the Upper Mississippi basin, and even beyond.

TABLE OF QUATERNARY FORMATIONS OF THE INTERIOR.

As we shall have frequent occasion in the course of this paper to refer to several of the members of the drift series and as the classification and the terms which we prefer to use at the present stage of investigation are somewhat different from those now commonly recognized in glacial geology, it may subserve the mutual convenience of the reader

[1] For convenience throughout this article we shall include under the term "driftless area" all that tract which is not overspread by foreign bowlders or pebbles, excluding the loess and neglecting the valley streams of sand and gravel which traverse the district.

and ourselves to here introduce a provisional classification of the Quaternary epochs, as expressed in the interior basin.

	Epochs.	Subepochs or episodes.	Attendant or characteristic phenomena.
I.	Transition epoch.	Not yet satisfactorily distinguished from the Pliocene.	
II.	Earlier glacial epoch.	First subepoch or episode.	Drift sheet with attenuated border; absence or meagerness of coarse ultra-marginal drainage drift.
		Interglacial subepoch or episode of deglaciation.	Decomposition, oxidation, ferrugination; vegetal accumulation.
		Second subepoch or episode.	Drift sheet with attenuated border; loess contemporaneous with closing stage.
III.	Chief interglacial epoch		Elevation of the Upper Mississippi region 1,000 ± feet. Erosion of old drift, decomposition, oxidation, ferrugination, vegetal accumulations.
IV.	Later glacial epoch.	First episode or subepoch.	Till sheet bordered by the Kettle or Altamont moraine.
		Episode of deglaciation.	Vegetal deposits.
		Second stage or subepoch.	Till sheet bordered by the Gary moraine.
		Episode of deglaciation.	
		Third episode	Till bordered by the Antelope moraine.
		Later stages	Marked by terminal moraines of undetermined importance.
V.	Champlain epoch		Marine deposition in the Champlain and Saint Lawrence valleys and on Atlantic border; lacustrine deposits about the Great Lakes.
VI.	Terrace epoch		Marked by fluvial excavation, notably of the flood plains of second glacial epoch.

The transition epoch is not yet sufficiently distinguished from the Pliocene to justify a very definite conception of its character and limitations, yet there are several classes of phenomena that indicate a notable lapse of time between the latest known marine Pliocene deposits and the earliest demonstrable deposits of the ice age. A considerable amount of erosion appears to have intervened between the deposition of the Pliocene beds of the plains and the earliest of the drift of that region. Professor Todd has recently identified Pliocene beds as far east as Frankfort, Nebr., within the drift area and in a region that apparently suffered much erosion anterior to the drift. The deep channels of the Paleozoic region of the Mississippi basin appear to indicate a stage of elevation antecedent to the drift period greater than that of the present. This elevation could scarcely have been contemporaneous with the depression which permitted the Pliocene accumulations on the plains. The deep sandy and gravelly deposits of the Lower Mississippi, commonly referred to as the "orange sand," seem to us, in the light of present evidence, to bear testimony in the same direction. They have been commonly referred to the Champlain epoch and regarded as products of the earlier glacial floods, but they are not true glacial gravels, so far as we are able to learn, either from the literature of the subject or from inspection at Port Hudson, La., Vicksburg, Miss., Memphis, Tenn., and Columbus, Ky. Even as near the drift border as the latter point, in a search of the fine exposures of even the uppermost and latest members of the series, we were unable to find a single pebble that indicated a glacial origin. We did not even find an instance of an Archean pebble, though we do not doubt the occasional existence of these, since they would presumably occur quite independently of glacial agency, for the headwaters of the Mississippi and its branches in Minnesota, Wisconsin, and Missouri, and in the Rocky and the Appalachian Mountains, pass over Archean terranes, not to speak of the granitic gravel that might be derived from the Tertiary beds of the plains, which abound in crystalline pebbles. The *occasional* occurrence of granite and greenstone pebbles would not, therefore, be conclusive evidence that the gravels were of glacial origin. The distinct characteristics of glacial gravels are requisite, but were not observed. The orange sand of the localities examined is made up almost exclusively of residual flints derived from the Paleozoic formations by surface decomposition. They everywhere bear the most striking characteristics of gravels of residuary origin. Secondary glacial gravels border the present Mississippi, and a comparison of the two classes may be made on the ground. It is further significant that streams whose basins lie entirely south of the glaciated field are lined in like manner with such gravels, whereas the tributaries of valleys filled by glacial floods are occupied by slackwater silt, because of the more rapid deposition of the glacial streams. While we, at present, incline to refer the orange sands and gravels of the Mississippi and tributaries to a period, or to periods, antecedent to the drift period proper, we here merely wish to open a question which seems to have been closed upon entirely inadequate evidence. This much at least seems to us certain, that the orange sands and gravels are not at all correlatives of the marine Champlain beds of the lake region. They are widely separated from them both in time and in the orographic conditions of their formation, and we urge that the current views be dismissed and the question reinvestigated.

Present evidence seems to us to indicate two main glacial epochs, separated from each other by a very considerable interval, during which an orographic change occurred amounting to an estimated relative elevation in the Upper Mississippi Valley of about 1,000 feet. The deposits of the two epochs differ from each other more widely than could be anticipated on the hypothesis that both are glacier products, which we support in the main. The earlier drift is characterized, in the interior basin, by a wide but relatively uniform distribution, manifesting only occasional and feeble tendencies to aggregation in morainic ridges. It is not bordered, except in rare instances, by a definite terminal moraine, but ends in an attenuated border. It is not characterized by the prevalence of prominent drumlins or other similar ridged aggregation. The phenomena of glacial erosion connected with it are generally feeble. Glacial striæ are indeed present, even in the peripheral portion, but the surface of the rock is not usually extensively planed. The whole aspect of the deposit indicates an agency which spread the drift over the surface smoothly, and relatively gently, with little forceful action. The drainage phenomena are also of the gentle order. We have yet failed to find evidence of very vigorous drainage connected with the older drift of the interior basin—except in osars and kames, whose conditions of formation were exceptional—but, on the contrary, abundant proof of slow-moving waters and imperfect drainage, indicating low slope of the surface.

The later glacial epoch, on the contrary, was characterized by strong glacial action, planing the rock-surface vigorously, even up to the very limit of its advance. The glaciers plowed up immense moraines about their edges, except on smooth plains whose slope was away from the ice movement. The drainage was usually vigorous, and immense trains of glacial gravel stretch away from the margin of the ice sheet, reaching great distances down the valleys and frequently filling them to great depths with well-assorted material. The vigorous action of the glaciers of the second epoch and the rapid drainage, in general, stand in marked contrast with the gentle action and imperfect drainage of the earlier epoch. One of the conditions that determined the distinction was probably the difference in elevation that characterized the two epochs.

The interval between these two leading epochs we regard as the chief interglacial epoch, representing a greater lapse of time and a greater change in the dynamic agencies of the age than the several other interglacial intervals, or episodes of deglaciation, which mark the complicated history of the ice age.

As belonging to the earlier glacial epoch, we recognize two drift sheets that have been described by the geologists of the respective States as occurring in Southwestern Ohio, Southern Indiana, Central and Southern Illinois, Eastern and Southern Iowa, Northern Missouri, Eastern Nebraska, and Southeastern Minnesota.

Between these occur, at numerous points, vegetal and ferruginous accumulations and other evidences of a non-glacial interval. To this horizon belong the larger number of deposits described under the term "Old Forest Bed," but very many vegetal deposits so referred do not, in our judgment, belong there, but are referable to several distinct horizons.

We still hold as an open question the precise method of deposition of some portions of the drift sheets of the earlier epoch, but this does not essentially affect their chronological distinctness, unless it shall be shown that the overlying sheet is contemporaneous with some of the deposits of the later epoch—a view toward which, at an early stage of our studies, we inclined, but which appears to be unsupported by gathering evidence.

The interval marked by the vegetal deposits was doubtless very considerable, though the mere accumulation of the vegetation does not indicate a geologically extended lapse of time. The ferrugination, oxidation, and decomposition of the lower stratum furnish better evidence, though of a class difficult of definite estimation. It seems probable that this interval was greater than the episodes of deglaciation of the later glacial epoch, though these are also marked by vegetal deposits, in part.[1]

The subepochs of the later glacial epoch are determined by the existence of distinct moraines which maintain their individuality over wide areas. Present evidence strongly favors the view that the two outer moraines of the coast region, those of Nantucket and of Cape Cod, are strictly identical with the two leading moraines of Dakota, the Altamont and the Gary—these marking, respectively, the first and second subepochs of the later glaciation. The third and later stages are less well characterized, and their acceptance as general phases of glaciation of sufficient moment to be ranked with the preceding is of doubtful propriety. Their apparent importance grows with increasing study, but as yet they appear to be subordinate episodes.

Under the Champlain epoch we include only those deposits which were approximately contemporaneous with the marine depositions of the Champlain Valley, rejecting entirely the view that the orange sand, loess, and general drift sheets of the Mississippi Basin belong to it. We are convinced that they have neither chronologic nor genetic coordination with the true Champlain deposits. We believe that current views need fundamental modification in this regard.

The sharply-cut terraces which have attracted attention and given name to the closing epoch have been chiefly carved from the flood plains of the second glacial epoch or from the lacustrine deposits of the Champlain epoch. The relatively few sharply-defined constructional terraces are of the same dates. The earlier drift formations have usually suf-

[1] In an article in the Geological Magazine, August, 1879, p. 360, Mr. McGee has described a thin discontinuous basal member concerning which we express no opinion.

fered so much dissection and superficial modification as to greatly obscure, or obliterate, the older terrace plains. Such terraces are detectible, but have usually commanded the attention of critical and experienced students only. They are not usually embraced among the terraces that have attracted most attention and established a place in the literature of the subject, though there are a few notable exceptions to this. The terrace epoch, as here admitted, only embraces the later, fresh-carved forms. The obscure, worn forms probably belong to earlier dates, presumably the transition and interglacial epochs, in the main.

CHAPTER I.

CORRELATIVE FEATURES AND STRATIGRAPHY.

GENERAL RELATIONSHIPS.

Form.—The driftless area takes the form of a rude quadrilateral, with unequal curved sides and blunted angles. Its four sides are not altogether alike in the character, the agency, or the time of their formation, so that the shape, though rude, has its special meanings. But of these it will be fitter to speak hereafter.

Its western margin, which forms its longest side, stretches along the Mississippi, reaching from near the affluence of the Chippewa River to the great bend of the Mississippi in Northwestern Illinois, the turn of "Cromwell's nose" on the eastern face of Iowa. This border is slightly convex westward, and faces the great Iowa and Missouri Valley belt of drift, the general trend of which is curvingly to the southeast, thus bowing around the driftless area. The northern border is gently incurved and faces a slight lobe of drift, that, in its backward reach, embraces the basin of Keweenaw Bay, to which, as a lobe, it may have owed its origin. The east side is likewise indented, because it was here encroached upon by the Green Bay ice tongue of the later glacial epoch. The southeast side is relatively short and nearly straight, if we disregard its minor sinuosities. This faces the great sheet of drift of Illinois and marks the right edge of the earlier ice incursions from the Michigan basin.

It thus appears that, in its very form, the driftless area indicates the encroachments it suffered on either hand, and suggests at once the significant relationships in which it stands to the glacial movements about it.

Location.—The relations of the area to present political divisions we may pass lightly, with the remark that it lies chiefly in the southwestern portion of Wisconsin, laps upon the extreme northwestern angle of Illinois, and extends very slightly across the Mississippi into the edge of Minnesota and Iowa. If we were to exclude from it the loess-mantled portions, it would be restricted almost entirely to Wisconsin.

Drainage relations.—Allusion has already been made to its situation in the immediate basin of the Mississippi and to its relationship to drainage systems. Its western border rests very nearly upon the Mississippi. Its northwestern angle lies near the union of the Chippewa Basin with that of the Mississippi, 250 miles from the source of the latter. In its central portion, it is traversed by one of the larger of the upper affluents of the Mississippi, the Wisconsin. It thus appears that the tract lies not only in the very basin of the Mississippi, but embraces the union of two of its larger upper tributaries with it. It is worthy of note that several other streams head in the drift region about the driftless area and flow into it. Such are the Black and Trempealeau Rivers from the north, and the Root and Upper Iowa on the west, while several others join the Mississippi on the very borders of the district. There is but a single instance of a river having its headwaters in the driftless region and flowing directly out of it, that exception being the Pecatonica, which starts on the southeastern edge and flows easterly to join the Rock River.

The valleys which enter the driftless area from the northward exposed it to invasion along three notable lines, viz: The valley of the Mississippi from the northwest, the basins of the Chippewa, Black, and Wisconsin Rivers from the north, and the Fox River valley from the northeast. To enter the region from the northwest, the ice needed only to follow the Mississippi River valley; to enter it from the north, having once mounted the heights south of Lake Superior, it needed only to creep down a southerly slope; to enter from the northeast, it had to rise scarcely more than 200 feet above the surface of Lake Michigan to cross the low, broad water-shed between the Fox and Wisconsin Rivers, which, in the later epoch at least, it actually did.

Topographic relationships.—Extending our view to its broader topographic relations, there lies 100 miles to the east the long deep trough of Lake Michigan, trending southward. One hundred and fifty miles to the north lies the great basin of Lake Superior, pointing southwesterly. One hundred and fifty miles to the west lies the trough-like plain that forms the divide between the Minnesota River Valley and the central depression of Iowa.

Turning now to surrounding elevations, we observe only one that seems of importance, and that is the elevated tract lying south of Lake Superior, whose crest line is 100 to 125 miles north of the driftless area. Towards the north, this highland stretches out two arms, the one forming the elevated peninsula of Keweenaw Point, which runs northeastward from a point due north of the westernmost portion of the driftless area; the other, taking its origin from a point north of the northeastern angle of the driftless area, extends northerly and northeasterly, embracing the Michigamme water-shed and terminating in the Huron Mountains. Between these rude arms lies the Keweenawan Basin, over against which, on the south slope, towards the driftless area, lie the Chippewa and Wisconsin Valleys. The crest altitudes of the highlands reach about 1,200 feet above Lake Superior, or 1,800 feet above the sea.

The basin of Lake Superior descends 1,000 feet below the surface of the water, giving a total relief of 2,200 feet. The bed of Lake Michigan is about 900 feet below its surface, or 2,100 feet below the highland summits. The basins of Lakes Superior and Michigan, therefore, descend 400 feet and 300 feet, respectively, below the sea level.

It should perhaps be observed that west of the driftless area, between the Mississippi River and the central basin of Iowa and Minnesota, there is a somewhat elevated tract of land. This is not conspicuous to the eye upon the ground, nor in the profile, nor indeed in its effects upon the drainage systems. Yet it appears, perhaps fallaciously, to have been influential in determining the course of glacial movement.

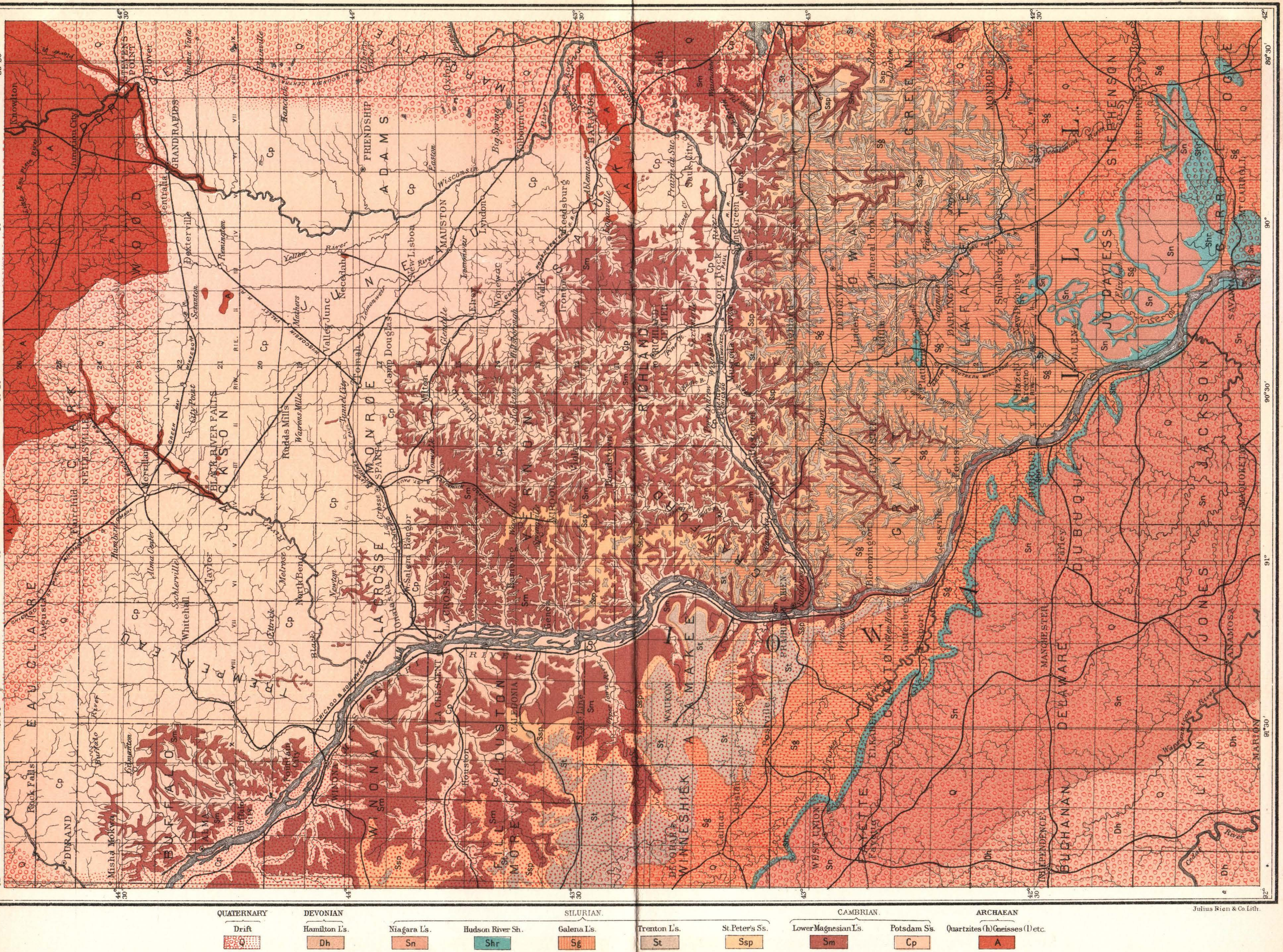
Summarizing broadly the topographic relations of the driftless area, there lie to the north and northeast the highlands of Northern Wisconsin and Michigan, and still farther to the north the great basin of Lake Superior; on the east, the depression of Lake Michigan; on the west, the shallow basin of South Central Minnesota and Central Iowa; while through the driftless region itself there course the great streams of the region.

Expressed in terms of altitude above the sea level, the following are the salient facts: The Mississippi River enters the driftless region at an elevation of about 650 feet above the sea and leaves it at about 575 feet. The average elevation of the driftless area, if reduced to a uniform grade by removing hilltops and filling valleys, is estimated at about 900 feet. The average summit level would probably fall a little short of 1,200 feet. The effective height of the highlands lying between it and Lake Superior is from 1,700 to 1,800 feet. The summit level between it and the central basin of Iowa and Southern Minnesota is about 1,300 feet. The surface of Lake Superior is 602 feet above *and its bottom* 400 *feet below the sea level.* The surface of Lake Michigan is 582 feet above *and its bottom* 300 *feet below the level of the sea.*

From the foregoing it appears that the relief of the region, broadly viewed, is not great. The highlands north of the driftless area rise only about 800 feet or 900 feet above the average level and are 100 miles away, so that the gradient by which they are reached is gentle. The summit level in Eastern Iowa and Minnesota barely rises 400 feet above the average altitude of the driftless region. The average surface of the driftless region is but about 300 feet above the surface of the Great Lakes, and is 1,200 or 1,300 feet above their lowest depths. We find our greatest contrasts between these depths and the highlands that lie in the angle between the two great lakes, where a range of 2,000 feet is found.

STRATIGRAPHY OF THE REGION.

The northern limit of the driftless area lies adjacent to the margin of the Archean tract of Northern Wisconsin, but barely reaches it on the Black and Wisconsin Rivers. It embraces several of the Archean knobs that protrude through the Paleozoic formations, the most important of which are the Baraboo quartzite ranges. From this basal Archean series the formations rise to the Niagara limestone, which is the latest lithified deposit embraced within the region. The included formations are the Potsdam sandstone, the Lower Magnesian limestone, the St. Peter's sandstone, the Trenton and Galena limestones, the Hudson River shales, and the Niagara limestone. The Archean formations at the base embrace, as we would classify them, Laurentian gneisses and Huronian quartzites and porphyries. The accompanying map, Plate XXIV, shows the distribution of these several formations. It need only be remarked that they curve concentrically about the Archean nucleus to the north, and so traverse the driftless region, coming in from a glaciated territory on the one side and passing out into a glaciated region upon the other. This is a condition extremely favorable for comparative studies upon the two regions. The whole group of Paleozoic beds dip gently to the southwest.



GEOLOGICAL MAP OF DRIFTLESS REGION AND ENVIRONS

BY T. C. CHAMBERLIN AND R. D. SALISBURY

(Pre-Quaternary Geology mainly from Wisconsin, Illinois, Iowa and Minnesota Reports.)

Scale 15 miles: 1 inch = 1: 950, 400.

5 0 5 10 15 20 25 30 35 40 45 50 55

CHAPTER II.

PRE-GLACIAL DEGRADATION AND RESIDUARY PRODUCTS.

EROSION AND ITS RESULTS.

In remarking that the several Paleozoic formations curve across the driftless area we have idealized the facts. An inspection of the map shows that the several formations exhibit tortuous contours as well as dissevered patches. These are the manifest results of drainage erosion. There was a time when the several dissevered areas of each formation were united into a common sheet, which embraced all the now scattered remnants and spread out an undetermined distance beyond.

Erosion history.— If it were possible to satisfactorily ascertain the lapse of time through which the region under consideration had been subjected to erosion previous to the glacial period and to determine its relative altitudes, it would be very serviceable, but only tentative opinions are permissible. We attach little weight to any view which we may form from the inadequate data now at command, but even a distant and imperfect approximation to the truth may be better than a mental blank.

As previously remarked, the latest marine formation of which we have any known remnant is the Niagara limestone. We have no direct and positive evidence that the region was submerged beneath the sea after that time. The limestones of the early part of the Niagara epoch cap the Blue Mounds and similar eminences that are scattered over the southern portion of the area and around its borders. But, though no higher formation has been found within the district, the middle Devonian strata now reach within about 35 miles of its southwestern border, and very possibly they once lapped upon it, though it seems to us improbable that the entire region that is now driftless was then submerged.[1] The Carboniferous strata reach within about 40 miles of the southern limit of the district, but we find no satisfactory grounds for believing that they ever overlay any part of it, though they probably closely approached its southern border.

Whatever may be true in respect to the extent of the incursion of the Devonian and Carboniferous seas, all the evidence that we are able to

[1] Geology of Wisconsin, Vol. I, p. 260.

to gather indicates that the region during those ages had but a slight elevation above the sea level, and hence was but feebly affected by subaërial erosion. This may not have been equally true of all stages, but it appears to be indicated for all stages known to us.

Concerning the interval that elapsed between the Carboniferous and the Cretaceous depositions there is little evidence. In the Cretaceous period the sea appears to have reached almost to the western border of the area, if, indeed, it did not actually encroach upon it, since in Iowa and Minnesota deposits believed to be Cretaceous are found in close proximity, though the continuous body of the formation lies 200 miles farther west. When we consider the present topographic attitude of the surface and remark the fact that the supposed Cretaceous deposits of Minnesota lie at elevations higher than the driftless area, we are led toward the belief that the Cretaceous seas must have overwhelmed the entire region; but when we consider that since the Cretaceous deposition the interior plain has been greatly lifted on the west and the surface inclination of the region reversed, and when we consider the further facts that no certain remnants of the formation have been found, and that the surface sculpture of the driftless region presents a different aspect from that of the Cretaceous regions of equal altitude and slope and indicates a higher antiquity, we are led in the opposite direction, and the preponderance of evidence seems to us to lie in this line, our judgment being—though we attach little weight to it—that the Cretaceous seas found their limit near the western border of the region in question and did not make notable deposits upon it.

But, whether submerged or not during these earlier ages, the driftless area was probably a low lying tract until the Tertiary age, and hence was subject to but slow and slight erosion. Some denudation, however, took place previous to this age. If theoretical considerations did not force us to assert this, we should be compelled to do so by the evidence which the unconformity of the Carboniferous strata upon the earlier ones presents in Illinois and Missouri, and by the manner in which the Cretaceous beds are inserted in hollows and gorges of the Paleozoic beds in Minnesota and elsewhere.[1] But, with all these qualifications, there can be little doubt that the present reliefs of the surface were mainly the work of post-Cretaceous times. The final sculpturing took place in the late Tertiary or in the period of transition to the glacial period. Most geologists, we think, would be inclined to regard the whole work as later and briefer than we do. But so long as the region lay near the sea level, as we infer that it did while the pre-Tertiary formations were being distributed about it, the work of denudation we

[1] Geology and Natural History Survey of Minnesota, 1872–'82, Vol. I, pp. 233, 280, 307–311, 343–345. It is not clear to us that the filling of gorges may not have been due in whole or in part to fluvial action in the depressed state of the surface attending the Cretaceous period, and therefore does not necessarily signify marine submergence.

conceive to have been only slight and rather of the nature of general degradation than of sculpturing into bold relief. This last could only have taken place when the region had become lifted so as to enable the streams to channel their courses deeply.

That such elevation took place before the drift period there is ample evidence. The old channel of the Mississippi was from 100 to 150 feet below its present bed, as shown by the artesian wells at La Crosse, Prairie du Chien, and Dubuque. The artesian well at La Crosse shows loose material to the depth of 170 feet; the one at Prairie du Chien, to the depth of 147 feet; the one at Dubuque, to the depth of 164 feet. The surface of the last is about 32 feet above low-water mark in the Mississippi, which makes the old bottom lie 132 feet below low-water mark.[1] This well is upon the western side of the valley, and perhaps does not represent the maximum depth. The well at Prairie du Chien is about 35 feet above low-water mark, making the rock bottom 112 feet below it.[2] The one at La Crosse is 46.59 feet above zero of the Government gauge, which is 643 feet above the sea.[3] The old bottom is here, therefore, 124 feet below zero of the gauge and 519 feet above the ocean. It is clear, therefore, that the Mississippi formerly ran in a channel more than 100 feet below its present one, the average of the above depths being 123 feet, while the average depth of the river is probably less than a dozen feet. Major Warren has called attention[4] to the depth of Lake Pepin as indicating the same general fact. On the border of Lake Koshkonong, 30 miles east of the driftless region, a well shows a former cañon at least 330 feet below the present surface of the Rock River, or only about 450 feet above the ocean. Rock was not reached. At Janesville, about 15 miles south of this, a well shows 350 feet of drift, which, subtracting for its elevation, indicates that the river is there flowing 250 feet above its old channel, which was about 530 feet above the sea. As rock appears at the surface within a short distance of each of these wells, it is not improbable that the maximum depth of the old valley was greater than that here indicated; indeed, the well at Lake Koshkonong makes it clear that this is true at Janesville. The valley drift is probably more than 400 feet deep east of that city. These facts, supported by other less tangible evidences, indicate either that the ancient streams had cut their channels to a lower gradient than at present or that the old elevation was greater. The old channel at Koshkonong is about 160 feet below the surface of the corresponding point on the Mississippi. The old Rock River, if running *on a bee line* to the Gulf, would have had an average fall of less than six inches per mile, under

[1] Data furnished by H. S. Hetherington, Esq., of Dubuque.

[2] Hon. Horace Beach, besides furnishing the above data, adds that two additional wells, sunk on ground 25 feet lower, reach rock at about the same level.

[3] Data furnished by Paul Heyse, Esq., city surveyor, La Crosse.

[4] Report of the Chief of Engineers, 1878, Part II, p. 911.

the present status of the crust and of the sea, or only four or five inches per mile by the actual course of the river, a possible condition of things, but not a probable one.

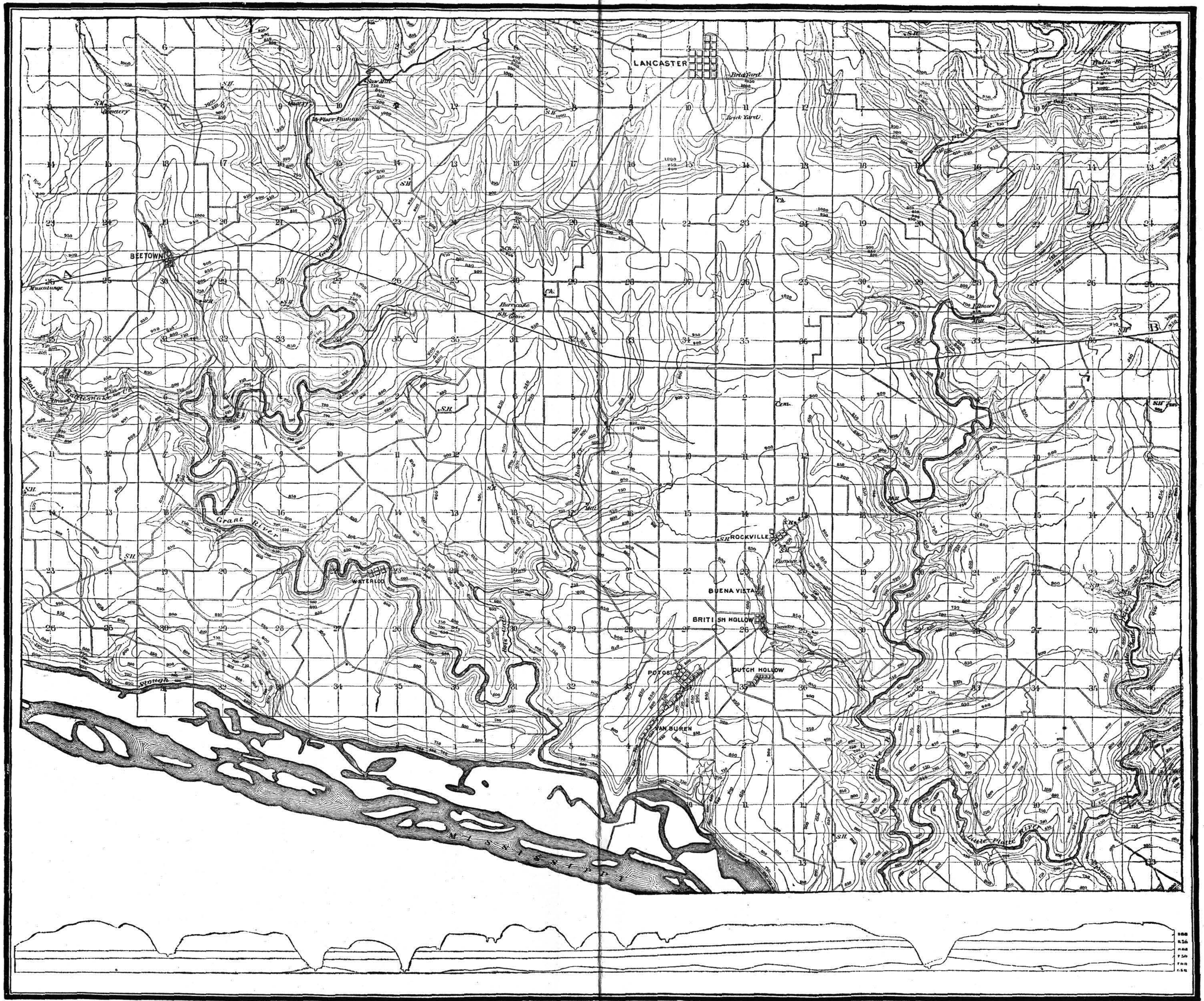
If we turn to the mooted evidence derivable from the adjoining Great Lakes and recollect that their beds are 300 feet and 400 feet respectively *below the sea level*, we find it necessary to believe either that the basins of Lakes Michigan and Superior were elevated some 500 feet above their present altitudes or that glacial corrasion or crust depression has been a large factor in their production.[1]

When we consider the very considerable amount of erosion which the Tertiary deposits in the Mississippi Valley below the mouth of the Ohio have suffered, as well as that which is displayed in the basins of the western tributaries, and when we recollect the extraordinary denudation of the Tertiary rocks of the western mountainous region, whose great orographic movements appear to have been felt in their vanishing effects throughout the Mississippi Basin, we find additional reason for believing that a very notable measure of erosion was accomplished during the closing stages of the Tertiary age and the transition period to the glacial epoch.

Whatever doubt may attach to the time, or times, at which the territory, now driftless, emerged from the sea, that doubt does not lie against the character of the surface first presented. It undoubtedly arose as a plain of great smoothness and regularity. Quite possibly the undulations which the strata now present were in some measure then developed; but, even if as great as now, they could scarcely have been detected by the eye. When first lifted, the plain was probably inclined to the south and southwest, the direction in which the beds now dip. The greatest elevation was at the north, centering in the Archean nucleus. A subordinate axis of elevation doubtless then, as now—but less developed—extended southward through the central portion of Wisconsin, giving the westerly element of the inclination of the beds. These initial inclinations determined the general course of the drainage of the region, while the minor undulations determined the tracks of the subordinate streams. The details of the establishment of the drainage system do not especially concern us here. It is only needful that we conceive a freshly emerged, smooth surface, gently inclined to the southward and southwestward and very gently undulatory. Upon this the rain and running waters began their work of attrition and solution, and sculptured the present reliefs out of the original plain. The work was almost purely one of degradation. The amount of upbuilding was too trivial to deserve attention, except in the partial filling of certain of the valleys.

The channelings which the surface suffered form an inviting though quiet field of study. They lack the overpowering immensity of the vast

[1] For a discussion involving details, see Geology of Wisconsin, Vol. I, pp. 253–259 and 288–291.



A TOPOGRAPHIC MAP OF A TYPICAL PORTION OF THE DRIFTLESS AREA

[Reduced from a map by Moses Strong, Wisconsin Geological Survey.]

erosions of the West. They do not stagger our imaginations by the magnitude of the phenomena. So, as well, they do not discompose our study with sentiments of awe and wonder. They lie within the range of easy comprehension. They are unimpassioned lessons on the methods by which the once expressionless face of the land was carved into a pleasantly diversified relief. We will first study the channelings and then the reliefs.

Channelings of the region.— As the rains fell upon the original plain, their surplus waters were turned hither and thither by trivial inequalities as they sought their way down its gentle slopes or were controlled by the gentle roll of its slightly undulatory surface. By the gathering of rills into rivulets, rivulets into brooklets, and these into larger and still larger streams, there developed upon the surface a ramification of drainage lines which joined each other as the twigs join the branches and the branches the trunk of a tree. When these lines were once fixed, the surplus of subsequent rains followed them and they became permanent guideways, which led the waters away to the ocean. With the lapse of time and the rise of the land, these were worn deeper and deeper until a complete channeling of the surface into ravines and valleys was accomplished.

In the driftless region by far the greater number of valleys belong to this simple class, being the products of erosion alone. Another class was developed at a late stage by the partial filling of these erosion valleys. These two classes may be considered in the order of their evolution.

Two varieties also arose from the character of the strata out of which they were carved, the one embracing those which were excavated from homogeneous rock, the other those which were carved from strata of unequal powers of resistance. Deferring the consideration of the last, which may be regarded merely as a modification of the first, let us observe the characters of valleys of simple erosion in homogeneous strata. Starting on any of the summits, which still show the early stages of development of the valleys, we find first on the descent a gentle depression, leading down to a well-defined ravine. These ravines, in the district in question, almost universally have gracefully-turned convex sides, curving down to a sharp valley on the one side and leading gently back to a well-defined summit on the other. We rarely find here the straight-sided, angular-browed, and V-shaped trenches that abound in the drift region. These beautifully rounded contours, associated with sharp ravines, signify three conditions: (1) a moderate relative elevation — for, if the altitude had been greater, the contours would be more abrupt and harsher; (2) moderate rainfall — by which every portion of the surface was softened and harmoniously degraded; (3) a considerable lapse of time, sufficient to etch deeply into the original plain, soften every contour, and reduce the whole to a sea of flowing curves; and yet the measure of time was not unlimited, else the steep gradients would have been reduced to low slopes or to actual base levels of erosion.

As we descend these ravines, they at first decline more rapidly; their slopes become steeper and more convex. In many instances the ravines cut into the rock, their freshets having swept away all superincumbent soil. This is clear proof that, in these instances, the work of degradation is still in rapid progress. In other instances the troughs of the ravines are filled with soil and surface débris, indicating that, though the work of degradation is still in progress, the waters bring down from the slopes at least as much detritus as the waters of the ravines can carry away. When the soil of a ravine is equally deep with the soil of the slopes and upland, we may safely infer that there is an equilibrium between the wash from the slopes and the transporting agencies of the ravine, and that the degradation of the surface is proceeding uniformly and harmoniously. When the rock is denuded, as in the former case, we may safely infer that the erosion is progressing more rapidly in the ravine than upon the slope, and that the former is deepening itself and increasing the inequalities of the surface. Occasionally the ravines are occupied by a greater depth of earthy detritus than the slopes and crowns, which clearly indicates that the ravines are overburdened by wash from the slopes and that the inequalities are lessening. While all these varieties are present, we estimate that the deepening of the ravines preponderates and that the inequalities in the upland tracts are being increased.

Flat-bottomed valleys.— Descending these ravines, their slopes decline less rapidly and their narrow bottoms widen and flatten until they grade into smooth-bottomed meadows, stretching from base to base of steeper ascents on either side. We may conceive the slopes of the ravine to have receded and a flat bottom to have taken the place of the mere, simple crease of the ravine.

The widening of the bottom is due to the low gradient which has been here reached in the progress of excavation of the valley. The running water now cuts but slightly on its bottom, because with the low slope at which it has arrived it is unable to promptly remove from its bed all the material which the steeper valleys at its head and the slope on either hand throw into it in times of freshets and heavy rains. In its struggle with this material it wanders to and fro and widens its valley more than it deepens it. This condition is an expression of the facts that erosion is measurably ancient and that the present rate of deepening of the valley is relatively slow.[1]

Silt-bottomed valleys.— Flat-bottomed valleys of this class grade downward insensibly into wider and flatter bottoms, which have had their ori-

[1] An acknowledgment is due to the suggestiveness of the discussions of Powell, Gilbert, and Dutton relative to the erosive degradation of the western mountainous and plateau regions.

gin in the actual silting up of previously deeper channels. On nearly all the tributaries of the Mississippi, the Wisconsin, the Black, and the Trempealeau Rivers, the lower reaches are found filled up with fine sediment laid down with beautiful lamination, stretching from bluff to bluff and forming level plains of great fertility. We have no positive measurements of the depths to which these tributaries have been thus silted, beyond the fact that the filling exceeds 50 feet in many instances; but by safe inference, from facts presently to appear, the depths in the larger valleys must have been double this amount at least.

If we follow down these silt-bottomed valleys to their débouchure into the broad valleys of the primary streams, the Mississippi, the Wisconsin, the Black, and the Chippewa, we find similar incontestable evidence that these were once much deeper valleys than now. These, however, have been filled by sand and gravel instead of fine silt. Following these back to the borders of the driftless area and beyond, we find their sand and gravel bottoms leading up to and ending against the great moraines of the later glacial epoch, and bearing incontestable evidence that they had their source in the icy floods that poured forth from the great glaciers of that period. The explanation of the whole series of bottom-filled valleys hangs here. The glacial streams poured forth into these channels a greater load of detritus than the waters were competent to entirely carry away, and it gradually lodged along the valley, building it up and ponding back the tributary streams, whose slackened currents were then unable to bear their lesser burden of silt, which was thrown down in the form of the laminated deposits above described. Thus, as the main arteries were filled with glacial gravels, the lateral tributaries were built up with finer silt.

Diversities due to stratal inequalities.—We have thus far neglected the diversities which spring from the inequalities of stratal resistance, which is a most important feature in this region. As above indicated, the stratified series embraces an alternation of soft beds—sandstones and shales—and of more resistant ones—the limestones. The easy excavation of the perishable strata caused a more rapid descent of the valleys in crossing their edges, and a more rapid lateral undermining of the slopes, resulting in wider valleys where the softer strata occur. The result is a rapid descent of the valley in crossing the horizon of each softer bed and the development along the valley sides of steep slopes or of vertical escarpments. The bare bluffs that face the principal streams are largely due to this cause. There are not infrequent instances, however, in which the meandering of a stream undermines the valley side and develops a precipitous cliff in resistant rock, in entire disregard of the inequalities of stratal endurance. Such are some of the bluffs along the Mississippi and many of its tributaries.

As the result of the easy erosion of the friable sandstones from beneath the capping of more resistant limestones, vertical cliffs and mural escarpments stand forth along the slopes of many of the valleys, and castellated outliers crown the brows of many of the hills like the feudal battlements of the Rhine.

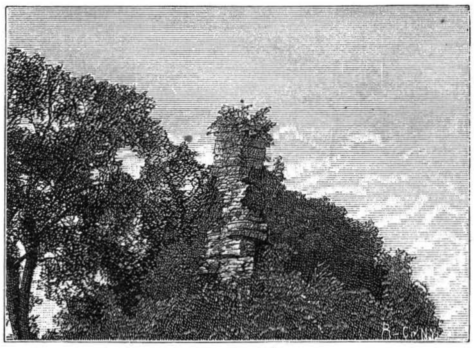


FIG. 27.—Erosion tower (Trenton limestone), Turkey River bluff.

Longitudinal profile of valleys.—The facts which we have previously stated, namely, the glacial filling of the great valleys, the ponding back and silting up of the tributaries, the formation of flat bottoms by an approach to base level, and the easy erosion of the softer strata, combine to give to many of the valleys of the region a special form of longitudinal profile that deserves notice. In the lower courses the slopes are low, and, in many instances, so continue well up to the headwaters of the streams, which rise frequently in springs at the base of an amphitheater of hills. From these points the valleys rise up promptly from one hundred to three hundred feet, to the summit level.

This is more especially true of the northern portion of the district in the horizon of the Potsdam sandstone, where the erosion has progressed relatively farther than in the southern region. The streams there have more extensively approached the meandering stage of degradation and the divides have been narrowed to sharper and steeper ridges.

In this respect the valleys of the driftless area stand in marked contrast with those of the surrounding newer drift regions. The valleys of the latter reach back by very moderate gradients to the divides *on* which, rather than at the base of which, they rise. They often run in shallow, scarcely depressed valleys, which bear in every contour the impress of recency and immature development.

The absence of falls in the driftless region.—The alternation of the hard and soft strata of this region furnishes a combination most facile for the development of cascades and falls in the course of the streams. Notwithstanding this, there is not a notable instance of such a phenomenon within the region, if we except the Black River Falls, which are embraced in valley drift. There are a few instances of low rapids, but they are rare, and a few small streams descend the quartzite ranges of

Baraboo with precipitous rapidity, but these scarcely rise to the grade of exceptions. This rarity, not to say absence, of falls is in contrast with their frequency in the adjacent drift-covered region. If we describe a belt around the driftless area equal to its own width, it will embrace a score of notable falls.

Now falls are the indices of youth. They are the expressions of rapid erosive activity, and that very activity hastens their disappearance. In obdurate formations they may have a greater endurance, but in soft strata their life is geologically short. In view of this fact, the presence and absence above noted teach us that the degradation of the driftless region has passed beyond the time of youth which permits cascades and falls, while the adjacent drift region has renewed its youth, through glaciation, in the formation of new valleys and new stream channels which have not yet passed the active stage of cascade erosion.

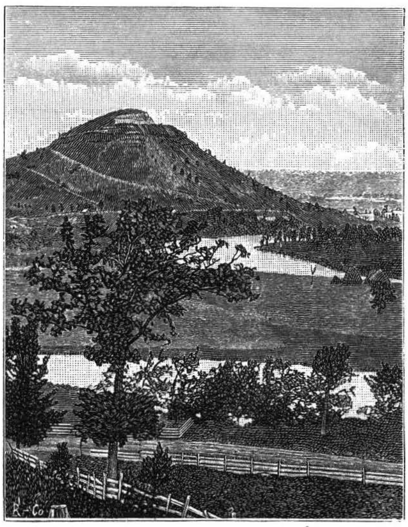


FIG. 28.—Topographic old age (driftless area).

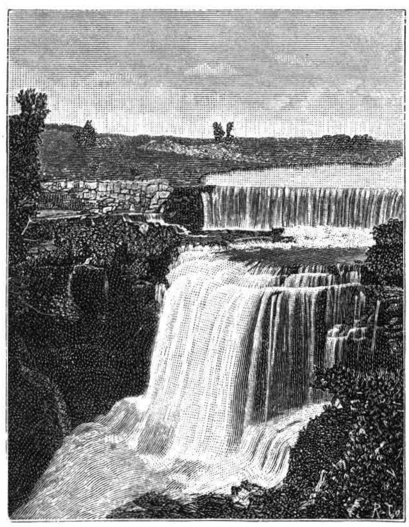


FIG. 29.—Topographic youth (drift area).

Rarity of constricted gorges.— Concordant with the absence of cascades is the rarity of constricted gorges. There are many deeply channeled valleys; indeed, these are characteristic of the region; but they are almost universally broad and capacious, and have been produced less by direct cutting down of the strata than by lateral wear due to the meanderings of streams in flat-bottomed valleys. Nowhere within the driftless region have we observed an instance of a constricted valley, indicating sharp, rapid channeling of the strata. On the very border, however, in the edge of the drift, are the remarkable dells of the Wisconsin River. This is one of numerous instances in the drift region where a river has been forced to develop a new channel because of the obstruction of its old one by the ice incursion. Since the glacial epoch the Wisconsin River has eroded a new channel and developed those exceptionally beautiful forms of fluvial corrasion which have made it a well-merited attraction to lovers of natural phenomena.

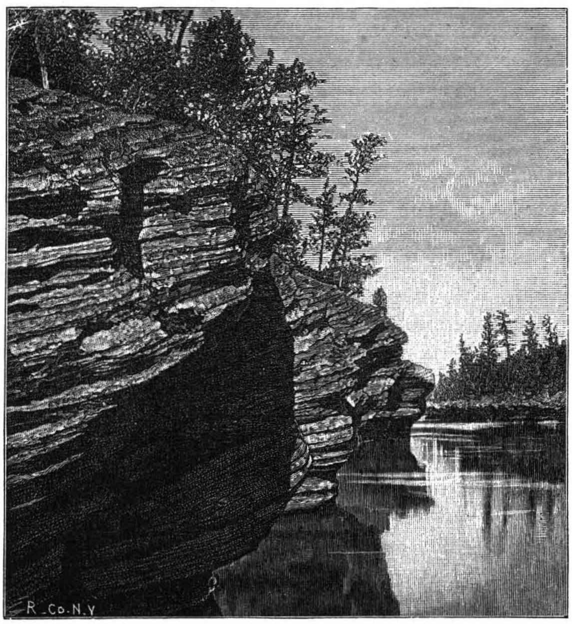
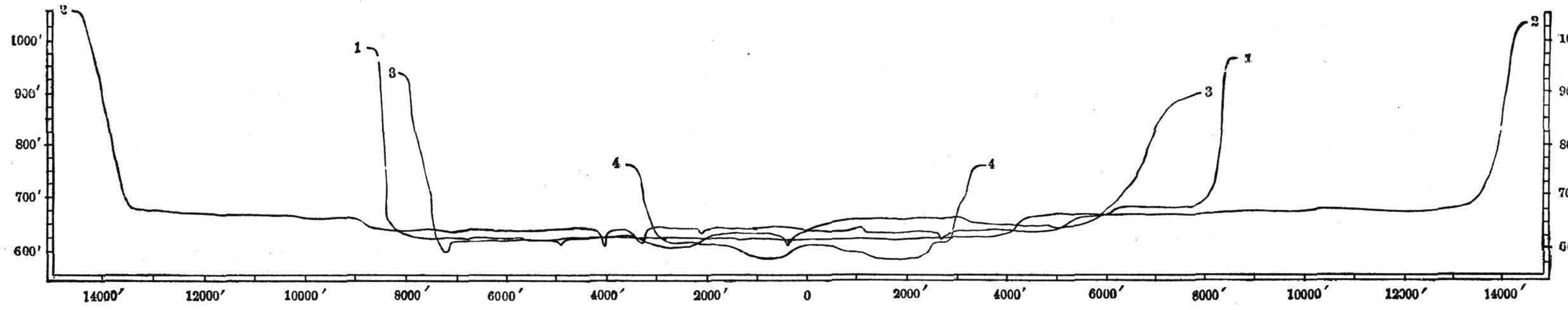


FIG. 30.—New channel of the Wisconsin River, "The Dells," near Kilbourn.

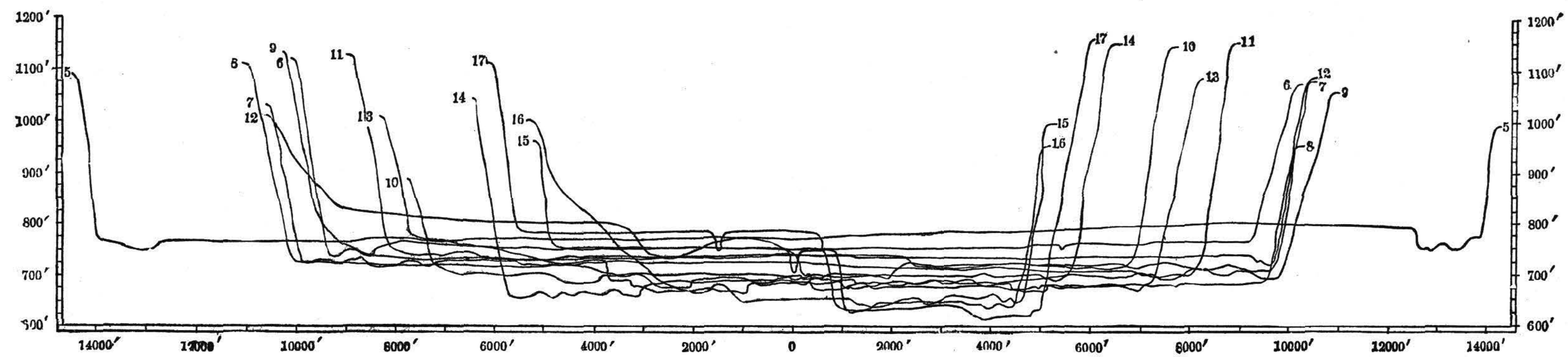
SPECIAL INSTANCES OF VALLEY SCULPTURE.

The Mississippi Valley.—The channel which the Mississippi River has cut across the driftless region is worthy of special attention, not only for the interest that attaches to its features themselves, but because of the remarkable contrasts which the valley presents in the several portions of its course.

In the glaciated region above the terminal moraine of the later glacial epoch, that is, above Minneapolis, the river runs through a drift plain not greatly depressed below the surrounding country. Below the moraines of the later epoch, between St. Paul and the edge of the driftless region, its channel is not markedly different from that in the driftless region, being but slightly modified by the mantle of drift thrown over it. Below the driftless region, it again holds its course for a distance of nearly 300 miles through a broad drift plain whose surface reliefs are inconspicuous. Through this plain it has cut a wide trench, averaging about 150 feet in depth. Beyond, it skirts the drift plain for nearly 100 miles, occupying a similar channel. Below this it enters



COMPOSITE PROFILE OF THE TRENCH OF THE MISSISSIPPI RIVER.



COMPOSITE PROFILE OF THE TRENCH OF THE WISCONSIN RIVER.

upon its great lower flood plain, 50 to 80 miles in breadth, cut into the sheets of loess and orange sand that formerly filled the valley. The special channel in all these portions, except that between St. Paul and the limit of the driftless region, is of later origin than that of the driftless region, which is really the only remnant of the ancient river left us. The general course of the stream is, with little doubt, that which it has had from a date much antecedent to the glacial epoch. But during that remarkable catastrophe its upper and lower regions were filled with drift and the drainage floods swept along courses from 200 to 600 feet above the levels of the present stream. Subsequently the special trench through which the stream now meanders was excavated, whether by one act, or more, we need not here consider. That this re-location does not correspond accurately with the earlier one is clearly shown by the rock barriers it has already discovered in its re-excavation. In the driftless region, however, the old channel remained unfilled, and there alone are we able to study, untrammeled, its ancient features, masked only by the slight mantling of loess and the slight degradation of the glacial epoch.

In the simplest view, the valley is a trench cut from 300 to 600 feet into the strata. In general, its walls are steep and its slopes relieved here and there by precipitous faces; but it is everywhere interrupted at short intervals by lateral valleys joining it on either side. These partake of its own characteristics in all their details. They only differ from the great channel itself in the element of magnitude and in the degree of progress they have made in the process of degradation. They manifestly form members of a common series having an origin and a history in all essential respects alike. The relations between the gorge of the Mississippi and its tributary valleys afford no ground for attributing the origin of the one to any conditions — whether of time, or of evolution, or of denuding agency — essentially different from those to which the others were subjected. We say no essentially different conditions. If we descend to minor considerations, some distinctions will be observable. We have before noted that the Mississippi and several of its leading tributaries, springing from the drift-bearing region, have valleys partially filled with glacial flood products. One result of this filling was to cause the streams to meander from side to side of their rising flood plains and to impinge upon the bordering cliffs, which they frequently undermined, destroying their slopes and leaving mural escarpments facing the channel. Along the Mississippi and along the tributaries thus filled, these freshly-formed faces are more common than along the tributaries not so affected by glacial floods. The total effect of this action, however, is relatively trivial. The projecting points of headlands were cut away in moderate measure; but the measure is only moderate. The remnant curves of the surface enable us to easily restore the original outline and to estimate with confidence the amount of encroachment. Fig. 31 illustrates a series of truncated headlands facing the valley at the point now occupied by Lake Pepin.

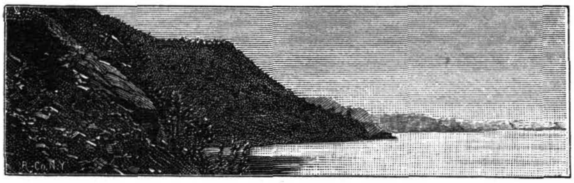


FIG. 31.—Truncated headlands, Lake Pepin.

The width of the interbluff valley is from one and one-fourth to seven miles. The average width along the edge of the driftless region is about three and one-fourth miles. The bottom is essentially plane. The sides rise abruptly on either hand to heights of 200 to 600 feet. Its capacity is estimated to be such that it would require a layer 25 feet thick to be taken from the entire surface of the driftless area to fill that portion of the trench which lies along its border. Fig. 32 is a photographic sketch of

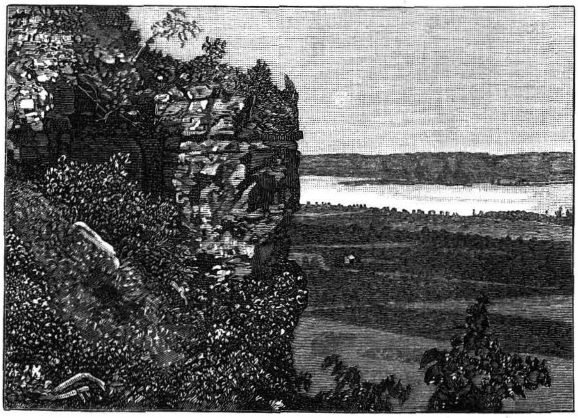


FIG. 32.—Trench of the Mississippi near its entrance upon the driftless area. Three miles wide; 400 feet deep.

the valley as seen at Lake Pepin, near where it enters upon the driftless area. Fig. 1, Plate XXVI, is a composite profile of the valley, formed by a combination of the profiles given by General Warren, reduced to a less exaggerated scale.[1]

The valley of the Wisconsin is but a lesser twin of the Mississippi. Its glacial flood bottoms have an average width of about three miles; its bluffs on either hand rise to average heights of about 375 feet. Its capacity is estimated to be such that it would require a layer of eight and one-half feet to be taken from the entire surface of the driftless region to fill the portion of the trench that lies in it. Its tributaries enter it by broad, flat-bottomed valleys in perfect accord with itself.

[1] Report of Bvt. Maj. Gen. G. K. Warren, Corps of Engineers, upon "Bridging of the Mississippi between St. Paul, Minn., and St. Louis, Mo.," 1876, Part II, pp. 900–1125; diagrams 1 to 29.

Fig. 2, Plate XXVI, is a composite profile of the Wisconsin River Valley compiled and reduced from Warren's profiles.[1]

The same essential characters are presented by other tributaries. In the northern portion of the district, occupied by the Potsdam sandstone, the erosion of the tributaries has progressed more rapidly, as above noted, and the valleys are relatively more capacious and present features concordant with the advanced degradation of the region. But when the conditions of excavation are considered these differences of features are demonstrations of concord rather than otherwise, since concord implies conformity to conditions of excavation, whether those conditions be of age or of ease of degradation.

Along the great rivers of the region there are many fine illustrations of combined ancient and modern erosion-contours. The ancient contours find expression in curves and moderate slopes, or, if the differences in the resisting power of the strata are so marked as to develop jutting cliffs by the sapping of the softer formation, these are worn and ragged by the long weathering to which they have been exposed. The newer contours find expression in abrupt declivities, fresh rock surfaces, and steep talus slopes. A beautiful illustration of the two in combination is presented by the "Sugar Loaf" at Winona, of which Fig. 33 is a sketch

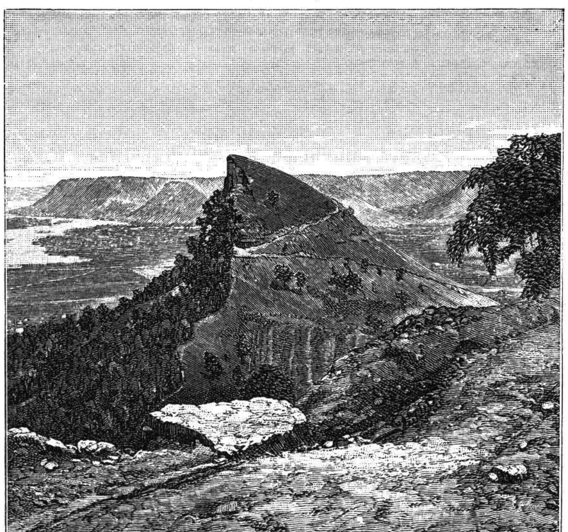


FIG. 33.—Combined ancient and modern erosion contours. "Sugar Loaf," near Winona, Minn.

from a photograph. On the right slope are the steep but symmetrical curves of the old erosion surface, on the left the precipitous rock face and the fresh talus slope of the later one, the two being separated by a

[1] Report of Gen. G. K. Warren, Corps of Engineers, upon the "Improvement of the Water-Transportation Route from the Mississippi to Lake Michigan along the Wisconsin and Fox Rivers," 1876, Part II, pp. 189–298; Plates I to IX.

sharply defined line. At the left of the sketch is shown the Mississippi, the agent which, in a not distant age, undermined the foot of the "Sugar Loaf" and carried away its northern half.

The reliefs of the region.—All the reliefs of the region have been developed by the sinking of the drainage lines into the original plain. The forms of the reliefs are, therefore, but the complements of the depressions produced by erosion. Only in the remotest degree can we discern that they arise from any other source. There are certain slight undulations of the strata, which, perhaps, originally corresponded to similar slight undulations of the surface when it arose from the sea and when first the drainage lines were located upon it. Thus very slight swells may have shed the waters into the slight depressions, and to that extent determined the courses of the streams. When once fixed they sunk themselves into the strata, carrying down with them all their tributaries, even to their smallest ramifications. In the process of degradation all the original surface undulations have been carried away, and they are not now features of the landscape. But the divides thus determined remained permanent and coincide with the greater ridges of the region. The most noteworthy example that seems to fall under this class is Military Ridge, which runs across the region in an east-westerly direction immediately south of the Wisconsin River, constituting the water-shed between it and the affluents of the Rock River. It is a notable fact that the head branches of the Rock River take origin along the south slope of this ridge for a distance of 100 miles. It is probable that the original courses of most of the leading streams were determined by such slight undulations of the original surface and that the present divides correspond with the original swells.

Forms of ridges.—Originating in this way, it is not difficult to understand how the drainage developed the dendritic system of valleys which characterizes the region. As these sunk deeper and deeper with the progress of erosion, the intermediate spaces were left standing forth in relief. In process of time these became the hills and ridges of the region. A typical ridge of the region consists, therefore, of a central elongated elevation more or less irregular, whose sides are flanked by a series of spurs, themselves supported by secondary spurs, so that the main ridge is buttressed and rebuttressed, until the series terminate in points jutting out into the adjacent main flanking valleys. One of the most typical instances of this structure is presented in the dividing ridge between the Kickapoo and Mississippi Rivers. Both have cut their channels deeply into the Potsdam sandstone. Between them there rises a massive ridge mounting up 400 to 700 feet above their flood plains. The summit is rounded and gently undulating, relieved here and there by projecting outliers of rock. From this central massive ridge there jut out on either hand stout, complex spurs, dividing into lower and subordinate ones in succession, until finally they drop down on either hand to the flood plains of the Kickapoo and the Mississippi. In plan, its contours resemble a deeply-lobate, compound pinnatifid leaf. The geological map plate conveys to the geologist, perhaps better than a contour map can, the character of this and similar ridges of the region.

This general type of structure presents, within the area under consideration, all stages of degradational development. In some districts there are broad ridges, on the summits of which the drainage has developed only the initial stages of this system of sculpture, and the crest plain is only pleasantly relieved of its monotony. Much more frequently, however, the process has extended so far as to give diversity to the region in well-rounded hills and ridges, with contours flowing in broad, graceful curves. But in some districts, especially in the sandstone regions, where the softness of the formation has hastened the progress of degradation, the inter-fluvial ridges have been cut back to sharp, abrupt crests, often deeply dissected, developing acute peaks and concave sky lines.

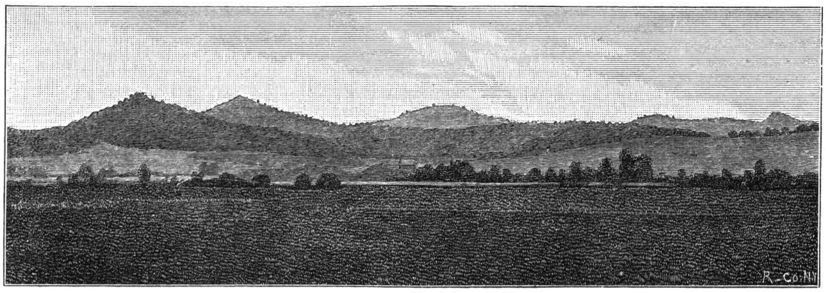


FIG. 34.—Ridges developing into peaks. Base level of erosion in the foreground. Near Ettrick, Wis.

By the further progress of the same processes of erosion, the ridges are cut across at intervals along their courses, leaving scattered lines of hills as representatives of the former continuous ridges. This stage may be seen in the northern part of the district, where the elevated lands terminate in isolated hills on the plains of Adams, Juneau, and Jackson Counties, of Wisconsin.

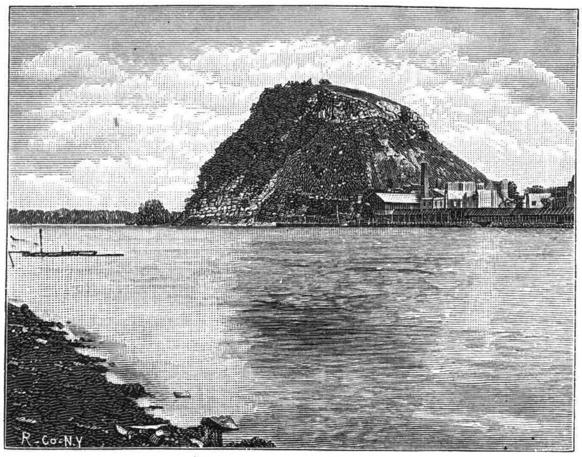


FIG. 35.—Isolated erosion hill, limestone crowned; shows also ancient and recent erosion contours. "Barn Bluff," Red Wing, Minn.

In the final reduction of these isolated hills there have arisen some very curious erosion forms, carved mainly from the Potsdam sandstone. The hills when first dissevered from the massive ridges, with which they were formerly connected, appear to have been mainly capped with Lower Magnesian limestone, which is, on the whole, more resistant than the underlying sandstone. A first stage of the degradational development consists of a protecting crown of resistant limestone, valorously maintaining itself while the beds around and below are yielding to degradation. The result is an isolated, steep-sided hill. For a suitable illustration we have gone just outside of the limits of the driftless region into the thin drift tract, from lack of a suitable photograph of one within, but equally good illustrations exist. At a further stage of degradation, the cap of limestone has been entirely removed, with its soil and vegetation, and there remains only the pedestal of sandstone. The upper portion of this, however, appears often to have acquired unusual solidity by solutions percolating down from the limestone cap now removed, and by the silicious induration which weathering often develops in outlying sandstone. The result is a rectangular form standing solidly forth from the common degraded surface about. Fig. 36 is an illustration of this type. With the progress of erosion the mass becomes dissevered into numerous more or less independent columns, which assume various fantastic forms according to the different degrees in which their several parts decay. The erosion proceeds chiefly along the joints by which the mass is traversed and along the lines of softer sedimentation, dividing the whole mass vertically and horizontally into bold projections and deep recesses. Fig. 37 is

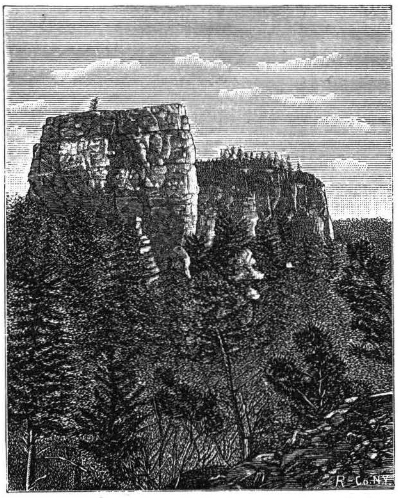


FIG. 36. — Rectangular erosion form; Potsdam sandstone; limestone crown removed. "Bee Bluff," northeast quarter of driftless area.

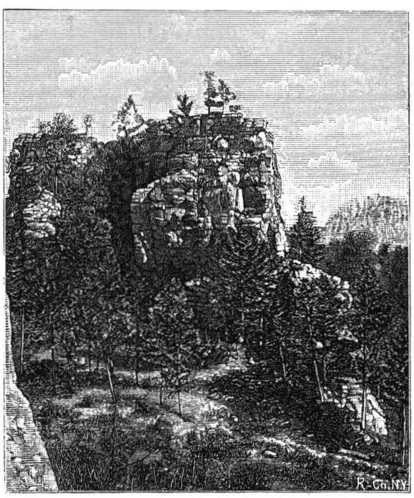


FIG. 37.—Rectangular form breaking down into columns; Potsdam sandstone; Fort Danger, northeast quarter of driftless area; Phantom Cathedral in the distance shows a more advanced stage of degradation.

one of scores of illustrations of this stage of destruction. Many of these fantastic castellated forms may not have passed through the rectangular stage above noted, but they are frequently so related to larger masses which still retain that form as to suggest that this is the usual order of evolution.

At a still further stage of advance the columns become almost completely isolated from each other and remain as natural towers, awaiting a final stage of destruction by which they shall be overthrown and the last remnant of the strata that once spread over the region be destroyed (Figs. 38 and 39).

FIG. 28.—A further state of erosion; columns approaching isolation. Giant's Castle, near Camp Douglas, northeastern part of driftless area.

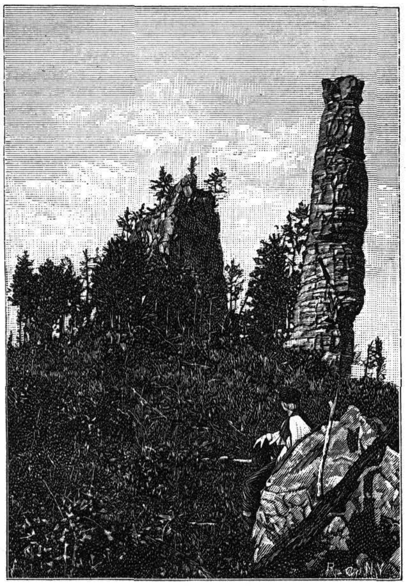


FIG. 39.—Final stage of isolation. Pillar Rock, northeast quarter of driftless area.

The ultimate result is a complete reduction to a basal plain of erosion closely analogous to the original one from which the evolution took its origin. It is old age declining again to the level of childhood; but the level of age and the level of childhood are not the same. When the strata were born of the sea they were fresh and perfect in their entirety. When, after an age of elevation, they have been brought again back to a similar level, they are worn and weathered; they have lost their integrity; they have been depleted of large parts of their substance; they are but the truncated remnants of once complete strata.

Evidence of non-glaciation.—One of the most convincing evidences that the region has never been invaded by glaciers is to be found in the fragile pinnacles of rock which abound over a somewhat wide area in the northern portion of the district. It is incredible that the ice should have passed over the region without modifying or entirely obliterating

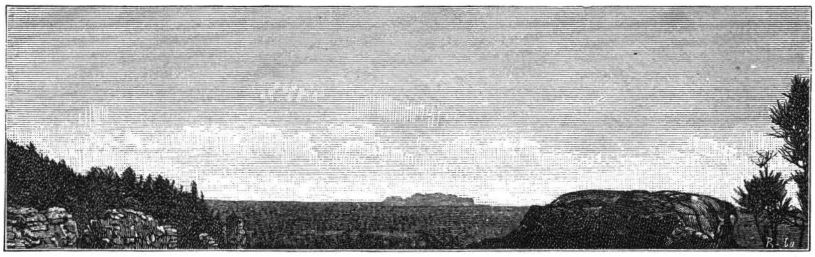


FIG. 40.—Basal plain of erosion, partially developed; northeastern portion of the driftless area.

the more slender forms. Contrast the foregoing features with the following sketch of the topography of the drift-covered region within ten miles of the border.

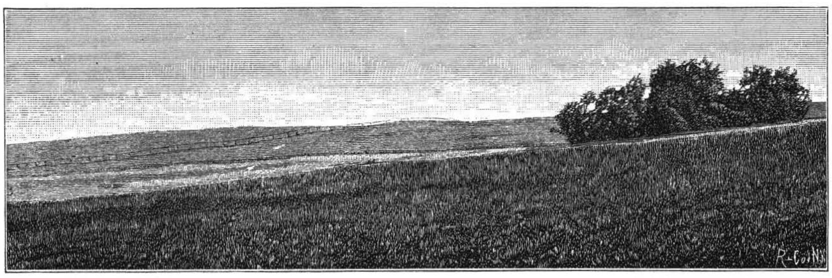


FIG. 41.—Typical drift topography; taken at a point within about ten miles of the drift border, west of Brooklyn, Wis.

Less striking, but not less convincing, are many of the other topographic features to which attention has been called. Taken altogether, the topographic features afford in themselves a most conclusive demonstration of the absence of ice invasions since they were formed. The erosion which has been involved in their production is altogether too great to permit us to entertain the view that they have resulted from post-glacial degradation. The amount of erosion which surrounding regions have suffered since the final retreat of the ice is quite trivial. It has not reached a sufficiently advanced stage of channeling to furnish complete drainage to the region, much less to set forth in isolated relief any of its formations. The erosion of the older drift surfaces adjacent to the driftless region is very much more considerable, but by no means sufficient for the production of these bold features in the strength and prevalence they here present.

There are a few exceptional instances within the tract covered by the thin edge of the older drift, where isolated outliers of similar nature exist. The most noteworthy is Castle Rock, near Farmington, Minn., which rises as an isolated peak to a height of 40 feet.[1] Although this lies within the region of attenuated drift, we are not as yet convinced that it was ever overridden by the ice, though we are unprepared to express an opinion upon the subject. It occupies the crest of a knoll, and bears evidence, in the sand that lies at its base, of considerable recent degradation, and hence we regard it as not impossible that this may be an instance of the development of an outlier subsequent to the earlier drift epoch. A similar, but less notable, instance occurs near Footville, Wis. The tower, in this instance, has a height of about 15 feet and stands at the foot of a low bluff of St. Peter's sandstone, from which it is not improbable that it has been dissevered since the earlier glacial epoch. It is altogether too slender in its present condition to have withstood any considerable lateral pressure. But these are quite exceptional instances and do not approach, in the magnitude of their forms or in the high development of their characters, the scores of giant cairns, towers, and castles that diversify the driftless district.

RESIDUARY PRODUCTS.

We have now glanced at some of the more notable results of the erosion which the region suffered. Its relief features are, in a sense, residuary products. They are the stratal remnants which the erosion of the ages has left. But the residuary products to which we now turn our attention embrace those earths and partially decomposed fragments of rock which mantle the surface of the region.

The process of degradation begins with the division of the rock by crevices into fragments of limited size, which then decompose in various degrees, forming sands and clays of diverse degrees of fineness. It is only when these stages have been reached that transportation ordinarily occurs. The mantle of earths and rock fragments which overlies the region represents that portion of the strata which has been disintegrated but not yet removed. It represents the degree in which

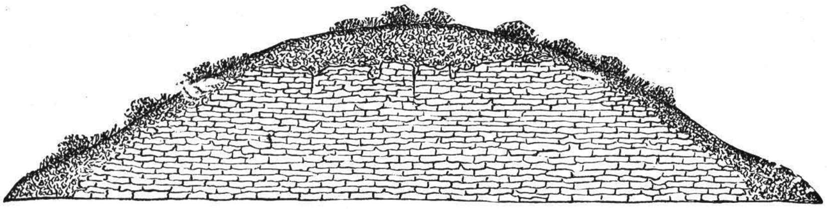


FIG. 42.—A typical section of the residuary mantle of a limestone hill.

transportation lags behind disintegration. There are many steep slopes and precipitous faces, a few very narrow summits, and the bottoms of a few of the sharper ravines, in which transportation keeps pace with

[1] The Geological and Natural History Survey of Minnesota, Vol. I, pp. 33, 58, 74, and 656.

disintegration and the bare rock is exposed. But, with these limited exceptions, a mantle of disintegrated material covers the whole region.

This material is essentially the residuum left by solution. The rainfall, penetrating the surface, carries with it well known solvent agencies derived from the atmosphere and from the vegetation on the surface. Attacking the rock, these solvents bear away the several ingredients which they are competent to dissolve and leave the rest behind. The disintegration thus effected takes place on the surface of the rock, along the crevices and cavities by which it is penetrated, and also in its capillary pores. The result is the production of well disintegrated earth at the surface, which graduates into partially decomposed rock below. At the very surface a more complete disintegration is effected by atmospheric agencies and vegetation, producing what is denominated soil, in distinction from clays and sands. This surface material is also continually subjected to wash, by which a partial assortment takes place, which aids in giving it the distinctive characteristics of soil. There is here also an addition of material derived from the decomposition of vegetable and, subordinately, of animal matter. Our limits do not permit us to enter at length upon these activities, but it is important to our general purpose to note the nature and amount of these residuary products. Fuller details of an extended examination of the character and amount of the residuary material of this region will be presented in a bulletin of the Survey now in preparation by Mr. Salisbury, and we will here indicate only the more general facts concerning it.

Physical characteristics of the residuary earths.—Throughout much of the driftless area, clay, using that term in its popular sense, is the most conspicuous residuary product. In many respects this clay is notably unlike that which owes its origin either directly or indirectly to the drift forces. Unlike drift clays it is never stratified. It also differs widely from drift clays in texture, color, constitution, disposition, and association.

The typical clay of the driftless area is free from the minute angular fragments of foreign rock which are to be found in glacial clays. Its texture is, therefore, more homogeneous, although it undergoes some changes in its vertical extent, as shown in numerous sections. Above, the clay graduates into soil, which outside the valleys is uniformly shallow. Beneath the surface soil, the clay loses the dark color of the latter, due to the presence of organic matter, but is for a certain distance downward not unlike the superior portion in texture. The deeper lying clay, where limestone is the subjacent rock, is the most characteristic member of the residuary earth series. It is not like that above, structureless, although, like that, it is without trace of stratification. It generally shows a tendency to cleave, breaking up into little pieces which are roughly cubical. This is often conspicuous, and especially so on the faces of sections which are thoroughly dry. In such situations large quantities of the clay in small angular blocks may be removed by slight friction. The size of the cuboids varies, within somewhat narrow limits, from a small fraction of an inch to one or two inches in diameter. This cleavage is probably a phenomenon of shrinkage due to drying, as it partially disappears when the clay becomes wet. This structure has given rise to the local name of "joint" clay, an appellation not altogether inappropriate.

Upon drying, this variety becomes very hard and rock-like. It only becomes adapted to serve as soil by surface amelioration, as is shown by the fact that, from the thousands of mineral holes scattered over the southern part of the mining district, the material ejected still lies beside the excavations as heaps of clay, without covering of vegetation, although it has been exposed in most cases for many years. Notwithstanding this fact, the clay, even in its deepest parts, wherever examined, is found to abound in minute perforations. These, in many cases at least, indicate the penetration of rootlets, for the rootlets themselves may sometimes be found. In some cases, too, the perforations have been seen to undergo a gradual variation in size, and to branch now and then, much as rootlets do. On the other hand, it is probable that some of the perforations have had a different origin, for in one case a small insect was found in one of the little canal-ways. The clay is exceedingly tenacious, and hence the perforations, once formed, would endure for long periods of time.

Another characteristic of certain portions of the clay is its power of retaining moisture. It can rarely be found, even in the driest season, unless exposed to the direct rays of the sun, without visible moisture a few inches from the surface. The regions where it is present are conspicuously less affected by drought than adjacent localities where it is wanting. For this reason it is a valuable subsoil.

Fragments of residuary rock are not uncommon in the deeper portions of this earth. Of these, chert fragments are most abundant, and occur scattered sparingly throughout the clay or sometimes arranged in more or less distinct layers in it. Even where they appear to be entirely wanting, the microscope often reveals minute flakes scattered sparsely throughout the clay. The larger pieces are more numerous near the basal portion of the clay than higher up.

It is natural to suppose that the residuary earths derived from the decomposition of limestone would differ very notably from those which take their origin from sandstones or from shales or mixed crystalline rocks. Yet the difference is far less than might be anticipated. There usually overlies the sandstone strata a loamy earth not very far removed in character from that which mantles limestones. It is somewhat more sandy, and consequently less cohesive, and presents the opposite variations in vertical sections, becoming less cohesive below, instead of more so. In the limestone region the toughest clay lies next to the rock. In the sandstone regions the soil graduates below into sand. The difference is most conspicuous where the mantle has been washed and redeposited and mingled with mechanically derived sand and secondary products, as occurs in some of the valleys.

We find little opportunity to observe the disintegration products of the shales, because of their limited surface exposure and because where exposed they form the lower slopes of limestone-capped eminences.

There are no metamorphic rocks in the region except the quartzite range of Baraboo. The residuary material which overlies this quartzite is not conspicuously different from that which overspreads the limestones and the sandstones. It is slightly less clayey than the former and more so than the latter, and presents less variation in vertical section than either. It graduates below into crumbling rock intermingled with clay.

This approach to likeness in these several residuary derivatives signifies that the process of formation is one which eliminates differences, first, by dissolving out soluble material, which forms one of the great differences between the parent rocks, and, second, by disintegrating the material to a more finely comminuted condition.

Formation of residuary earths.—The material of the Paleozoic strata was derived from the earlier Archean formations. Hence, directly or indirectly, the source of the residuary material is found in the ancient crystalline rocks, and they furnish an excellent basis for an elementary study of the origin of residuary material. They are composed mainly of quartzite and complex silicates. There are, to be sure, other constituents, as magnetite, calcite, &c., but they may be neglected. In the decomposition of the rock, the quartz remains largely unaffected, except that it is separated from its associates and mechanically reduced, more or less, according to the agencies to which it is subjected. The quartzose element of the residuary product is, therefore, coarse or fine, according to the original size of the quartz grains and the degree of comminution they suffered from fracture and abrading agencies. The complex silicates, on the other hand, underwent a very different process. The alkaline bases, which form a part of their ingredients, rendered them subject to decomposition. In this process the more soluble bases were removed, while the less soluble and simpler silicates were left. The complex silicates, therefore, instead of giving rise to comminuted particles of the same kind, as in the case of quartz, underwent decomposition, and the resulting particles were molecularly unlike the original. The process was not simply a separation of particles, but a disintegration of molecules, though the particles seen under the microscope are obviously not simple molecules. While they are much smaller than simple mechanical comminution would be likely to produce, they appear to be definite aggregates—i. e., firmly coherent particles—but whether this coherence was retained through the vicissitudes of molecular change or was acquired subsequently we do not know.

In the disintegration of the Paleozoic rocks these two classes of residuary products are reproduced. In the case of quartzose sandstones, the disintegration results mainly in the further reduction of the quartz particles. The sand grains are somewhat dissolved or etched by solution and somewhat broken by the various weathering agencies, so that there results a product finer than the original. But the residuary product has essentially the same chemical and mechanical constitution as its parent formation. In the case of limestones and dolomites, the lime and magnesia, together with such alkalies as may be present, are dissolved away by meteoric waters, and the residuum consists of such clay and quartzose matter as was embraced in the limestone. This insoluble matter we suppose to have been mechanically mixed with the limestone and not chemically united with it, as in the case of the silicates. The separation of clay from limestone is not, therefore, a process precisely similar to the production of clay by the decomposition of silicates. For the most part, the clayey matter of the limestone is in essentially the same state as when separated from the Archean crystalline rocks, and the decomposition of the limestones and dolomites has only restored it to the condition in which it was when deposited with the gathering calcareous sediments. But, in so far as it may have been in the form of complex silicates, it was probably degraded to the condition of a simple silicate, mainly silicate of alumina.

With all the clay there is undoubtedly commingled a large percentage of very finely comminuted quartzose particles, which have arisen from the mechanical subdivision of larger quartz particles, as above indicated. The residuary earths may therefore be conceived as a mixture of comminuted quartz particles with the true clayey particles which resulted from the chemical degradation of complex silicates, and whose particles in their individual state are of extreme minuteness. These minute clay particles appear to possess a strong disposition to unite by cohesion into more considerable lumps, and on the first inspection of clays these aggregations are very likely to be mistaken for ultimate particles. To break these down and to separate the individual particles from each other requires much care and patience. It is doubtful whether the truly ultimate particles are ordinarily reached in microscopic observations. Theoretically they may be minute beyond the reach of our best appliances. Practically, the greater care we exercise in separating the particles, the more do minute particles multiply, until the number lying on the very verge of vision is vastly increased.

We conceive that it is to these exceedingly minute particles that the impervious character of the clays is due. So long as in the aggregation of particles the interstitial spaces remain sufficiently great to admit of free capillary penetration, porosity remains, but when the interstitial spaces are reduced below the limits of free capillary action, an impervious character results.

Now, in all our common earths a certain considerable percentage of the particles are of such a size that if congregated without admixture of finer particles they would leave interstitial spaces sufficiently large to admit of a ready inter-penetration of water. But associated with almost all common earths there is a large percentage of much finer particles, which, insinuated among the coarser ones, fill up to a greater or less degree the interstitial spaces. When the percentage of these fine particles is sufficient to completely fill the interstitial spaces, and when these finer particles are so minute that their own interstitial spaces are below the limit of free capillarity, then the earth becomes impervious and we designate it a clay.

Microscopic character of residuary earths.— So far as our microscopic observations of residuary earths have extended they reveal the fact that in those derived from the decomposition of limestone, coarse grains are rare. There are occasional flakes of flint and rarely instances of rounded grains of quartz, but the residuary earths are mainly composed of particles much too small to be designated sand. Not only are the particles much smaller than sand grains, but they are also quite unlike them in shape and contour. Instead of being round, or at least more or less deangulated, as sand grains generally are, the minute physical elements of the earth are often conspicuously irregular in shape, as observed by Sorby and others. Even when sand grains retain some angularity of form, their surfaces generally bear witness to the smoothing action to which they have been subjected. Not so the particles of the earths. Even when their form is globular, their surfaces are, as a rule, uneven, often appearing like irregular fracture surfaces. At least this is true down to the limit of distinct vision. Of the smallest particles visible we have not found it practicable to determine surface peculiarities.

The ultimate constituents of even the darkest-colored clays are, almost without exception, transparent. They are generally slightly stained, but opaque particles are very rare. This is not true of the drift clays, in which minute opaque grains are not uncommon. The staining of the grains is probably largely due to iron oxide, as indicated by the amount of the iron content and by decolorization under the influence of chemical reagents.

Specimens of earths from numerous localities have been subjected to somewhat careful microscopic examination. The selections for study were chosen from such localities as were supposed to be mantled only by the purely residuary products, and, while they represent a somewhat extensive area, they may be said to have been taken mainly from the heart of the driftless tract and at elevations such as to avoid all suspicion of deposition from water during submergence, *unless* such submergence affected essentially the whole area.

The method of study adopted involved the determination of the physical character of the earths, the size, shape, surfaces, &c., of their particles, with a view to comparison with other earthy products, and the determination, so far as possible, of their mineralogical constitution. Many of the particles are too small to be determinable by methods at command. The finer portions of the earths were, therefore, separated from the coarser, and the determination of minerals has been based entirely upon the latter. The results of the microscopic study cannot be said to have been exhaustive, but some facts have been determined which are not without interest and significance. These facts are not what were, at the outset, expected. It should be kept in mind that the underlying rock is in all cases limestone, Trenton or Galena, and the residuary earths, so far as they are strictly residuary, must have taken their origin from one or the other of these formations.

With a single exception, all the earths examined reveal the presence of minerals apparently derived from the Archean crystalline series. The single exception is an earth taken from the surface of the decomposing limestone on a bald upper slope, the higher portions of which, as well as the crust of the ridge above, were nearly devoid of earthy covering. The minerals most commonly present are plagioclase feldspars, orthoclase, micas (both biotite and muscovite), hornblende, magnetite, augite, and epidote (?).[1] Quartz is universally present, and is much more abundant than all the others—indeed, in most cases it constitutes the bulk of the coarser portion of the earths.

Not every specimen examined shows all the above minerals, though several of them are present in nearly every specimen studied. Magnetite and hornblende are most nearly universal, but the feldspars and micas are also very generally found. Augite has been recognized in but few cases, and epidote but once, and that perhaps doubtfully.

An examination of specimens of loess from the region bordering the driftless area on the west shows that this deposit contains the same minerals, and, in the several specimens studied, no minerals, dolomite excepted, have been determined which have not also been found in the residuary product. Not only this, but their abundance relative to each other is practically the same in the two series of specimens and among different members of the same series. In those specimens in which magnetite is abundant, feldspar, hornblende, and mica are also abundant, and where any one is rare the others are commonly reduced in numbers correspondingly. The size, too, of these particles is almost identical, whether taken from the loess or from the driftless tract. The largest do not commonly much exceed .1^{mm} in diameter, and those one-fourth that size are much more frequent than larger ones. In shape there is no determinable distinction between the particles from the two sources. In both they are angular, sometimes showing fracture surfaces only, sometimes cleavage only, and sometimes both.

The total amount of these minerals is much greater in any given quantity of loess than in an equal quantity of the residuary earth, though there is hardly more difference in this respect between loess

[1] We are under obligations to Prof. C. R. Van Hise for aid in the mineralogical determinations. Without his confirmatory identifications we should have some hesitancy in asking confidence in our own.

and certain earths than between these latter and certain other earths selected with reference to this comparison. The inconstancy in quantity of these minerals in the earths is one of the notable facts developed by the microscopic study. This inconstancy is not, however, without law. In the apparently residuary mantle the superficial portions contain a markedly larger ingredient of the foreign materials than do the deeper-lying parts. This is true in every instance where two specimens from the same vertical section have been studied. On the other hand, the upper portions, in which these abound, are wholly, or almost wholly, wanting in bits of flint and chert, which are characteristic of the deeper portions. To cite a single illustration: in a comparison of material taken from three feet below the surface with other material from the same vertical section five feet lower down—one foot above the rock surface—it was found that the number of particles above $.02^{mm}$ in diameter was greater in the deeper-lying earth than in the more superficial. The greater portion of the particles more than $.1^{mm}$ in diameter were found to be almost wholly chert or flint. The proportion of particles between $.02^{mm}$ and $.1^{mm}$ in diameter was found greater in the more superficial earth than that of the greater depth. Now the coarser particles of the loess range, for the most part, between $.02^{mm}$ and $.1^{mm}$, relatively few particles reaching the latter size, thus indicating an approach of the superficial earth to the loess.

In the loess, rounded grains of sand are not wanting, and these may range considerably higher in size. Indeed, grains less than $.1^{mm}$ in diameter are rarely rounded, and sand made up of particles of several times that diameter would still be regarded as very fine sand. In the residuary earths, too, or at least in some of them, rounded sand grains are found, but, as compared with the other ingredients common to loess and residuary earths, sand grains are relatively much less common. As with the particles of feldspar, hornblende, &c., the rounded grains are of more common occurrence near the surface than in the subjacent portions.

The question of the source of the minerals present in the earths is conceivably susceptible of several answers. If the so-called residuary earths be strictly residuary, the origin of the hornblende, feldspar, magnetite, &c., must be sought in the underlying limestone. Such examinations of this rock as it has been possible to make with this in view have given but negative results; but they have been too incomplete to be decisive. Specimens of earths taken from pockets and seams beneath the surface of the rock, but rendered accessible by shafts, have in two cases shown the presence of one of the above minerals, viz, hornblende. It is possible, and perhaps to be expected, that surface particles would be carried down to some extent by drainage and the burrowing of animals, and it is also possible that these foreign particles may have found lodgment below, subsequent to the opening of the shaft; still their presence, even sparingly, in the deeper earths generally, may seem to lend some support to the idea that the limestone is their source. Against such an explanation, however, there is strong evidence.

In the first place the study of different specimens from the same vertical section seems to point to the conclusion that the upper portion cannot be derived from the lower. Data bearing on this point have already been given. If this tentative conclusion shall stand the test of further research, an extraneous origin for the feldspars, micas, and their associates must be sought.

But even in the superficial earths their distribution is by no means uniform. In some regions these minerals are relatively abundant, in others relatively rare. To account for this on the basis of local origin, the limestone must be supposed to have been correspondingly richer in these minerals at some points than at others, and, when it is considered that the parts requiring the greater supply of these minerals are largely the parts farther from the source of supply, there is no manifest reason for this. Furthermore, the residuary material becomes richer and richer in these ingredients as the border of the loess to the west is approached, and it would be strange indeed that the limestone should be rich in mica, hornblende, feldspar, and magnetite along the border of the loess and relatively less so with increasing distance from that border.

On the supposition of an extraneous origin of the minerals which we are warranted in calling foreign, it is conceivable that they may have reached their present position in either of two ways: they may have been transported by the wind or they may have been deposited from water. The region to the southwest of the driftless area—the direction of prevailing winds—might easily have furnished the material, which after deposition would have become commingled, to a greater or less degree, with the strictly residuary material by the burrowing of animals and by inwash in cracks and the tubelets left by decayed roots and by other means, and so might have given rise to the product which we now find. On the other hand, if the supposed loess-depositing waters, which—the aqueous hypothesis granted—certainly overtopped the bluffs east of the Mississippi, extended over the whole area, they would to some extent have stirred up and redeposited the pre-existent residuary material and would have added the foreign ingredient which is now found. If the submergence were but temporary, the result must have been very similar to what is now found. The manner in which the loess-loam fades out east of the Mississippi, as subsequently described, is quite in harmony with this conclusion. At the same time it is to be noted that this distribution is also just what would be expected on the supposition that the wind was the transporting agency.

The loess contains a notable ingredient of dolomite and calcium carbonate, both of which are wanting, for the most part, in the residuary earths. This will surprise no one who is familiar with the loess border and has seen the typical loess gradually become less and less dolomitic as one advances toward its limit, until it becomes a loam and finally altogether ceases to give evidence of the presence of carbonates. While no dolomite has been detected in the surface portion of the earths from the central portion of the driftless area, it has been detected in minute quantity in those earths which lie near the loess border—if it may be said to have a border—even where the amount present is too small in quantity to be indicated by the field test.

Size of particles.—A series of microscopic measurements of the sizes of particles of residuary earths, glacial clays, and loess was undertaken with the view of ascertaining what distinctions could be found between the products of disintegration and of glacial wear, and between those that have been transported by ice or water—and so perhaps assorted in some measure—and those that have not.

While these microscopic mensurations have not been pushed to an exhaustive extent, either in respect to the samples studied or the number of specimens necessary to be fully representative, a few specific results may forecast the nature of the ultimate determinations. Out of 158,522 measured particles from several representative localities, only 929 exceed .005^{mm} in diameter. From this it will be seen that only about .6 of 1 per cent. of the particles are so much as .005^{mm} in diameter. Five samples of purely residuary origin gave the following low percentages of particles having a size equaling or exceeding .005^{mm} in diameter: (1) .66 of 1 per cent.; (2) nearly 1 per cent.; (3) .6 of 1 per cent.; (4) .2 of 1 per cent.; and (5) .75 of 1 per cent. A fairly illustrative sample from near the rock surface at Mount Horeb, Wis., gave, in a single microscopic field, the following showing:

Particles less than .00285^{mm} in diameter	15,152
Particles between .00285^{mm} and .005^{mm} in diameter	208
Particles more than .005^{mm} in diameter	54

None of the 54 reached so great a diameter as .01^{mm}. Of the 15,152 probably 90 per cent. in numbers are less than half the size indicated. With a higher power it was estimated that fully half the particles fell below .001^{mm} in diameter, and it is not certain that the inferior limit in size was ascertained, since the visible proportion of exceedingly fine particles was greatly increased with each increase of magnifying power and the number at the limit of vision was always great. It seems certain, therefore, that the above figures must err on the side of coarseness, fine as the particles are. It should be added that in some of the clays particles much coarser than any here enumerated occur, but their number is insignificant, though their character is not. It should be kept in mind that the disproportion between the coarser and finer particles is much less, volume for volume, than the above figures would indicate, but the actual bulk of the particles under .005^{mm} must greatly exceed that of the particles of larger size. This is significant when considered in connection with the constitution of the loess, as shown by microscopic examination.[1]

Chemical constitution of the residuary earths.—The residuary earths, being formed by disintegration and solution, are almost completely depleted of the soluble ingredients of the rock, namely, the alkalies and alkaline earths, chief among which, in the limestone regions, are the calcic and magnesic carbonates. The chief residual elements are quartz, the undecomposable silicates, and ferric oxide. Physically these are combined in different proportions, taking the form of clay and sand, more or less intermixed with coarser ingredients, the clay being the aluminous and comminuted siliceous material that was disseminated through the limestone, the sand being the minute but appreciable quartz particles, and the coarser material being in large part fragments of flints, the degraded residue of the silicious concretions of the parent formation. The absence of calcic and magnesic carbonates, except in inappreciable quantities, has been proven by thousands of field tests and confirmed by numerous partial analyses and by several exhaustive ones. The drift clays, on the other hand, have been ascertained to be calcareous by unnumbered field tests, confirmed by laboratory analyses, which show that in some instances 40 per cent. or more of the clays consists of comminuted magnesian limestone. The drift clays are, in short, rock flour, and not, as are the residuary earths, the product of rock rot.

The following complete analyses of typical specimens of residuary clays, made by Mr. R. B. Riggs, under the direction of Chief Chemist F. W. Clarke, indicate their general composition. Nos. 1 and 2 are from the same vertical section, the former being four and one-half feet from the surface, and the latter eight and one-half feet and in contact with the underlying limestone. Nos. 3 and 4 are related in the same way, the former being three feet from the surface and the latter four and one-half feet, the lower sample, as before, lying in contact with the rock.

[1] Since the above was given to the printer the number of measurements has been greatly increased, as indicated in the following summation of additional data:

Particles less than .0025^{mm}	721,866
Particles between .0025^{mm} and .005^{mm}	9,812
Particles over .005^{mm}	634
	732,312

Of those above .005^{mm} in diameter, particles reaching .06^{mm} are not rare. Almost all above .1^{mm} are fragments of flints and cherts, and these grade up into the chips and flakes of flint of notable sizes that abound in many parts of these clays, being derived from the nodules of the cherty limestones.

Analyses of typical specimens of residuary clays.

No. 1.		No. 2.		No. 3.		No. 4.	
SiO_2	71.13	SiO_2	49.59	SiO_2	53.09	SiO_2	49.13
Al_2O_3	12.50	Al_2O_3	18.64	Al_2O_3	21.43	Al_2O_3	20.08
Fe_2O_3	5.52	Fe_2O_3	17.19	Fe_2O_3	8.53	Fe_2O_3	11.04
FeO	.45	FeO	.27	FeO	.86	FeO	.93
TiO_2	.45	TiO_2	.28	TiO_2	.16	TiO_2	.13
P_2O_5	.02	P_2O_5	.03	P_2O_5	.03	P_2O_5	.04
MnO	.04	MnO	.01	MnO	.03	MnO	.06
CaO	.85	CaO	.93	CaO	.95	CaO	1.22
MgO	.38	MgO	.73	MgO	1.43	MgO	1.92
Na_2O	2.19	Na_2O	.80	Na_2O	1.45	Na_2O	1.33
K_2O	1.61	K_2O	.93	K_2O	.83	K_2O	1.60
H_2O	*a*4.63	H_2O	*a*10.46	H_2O	*a*10.79	H_2O	*a*11.72
CO_2	.43	CO_2	.30	CO_2	.29	CO_2	.39
C	.19	C	.34	C	.22	C	1.09
	100.39		100.50		100.09		100.68

a Contains H of organic matter. Dried at 100° C.

The following analyses of drift clays, made by the same chemist, are instructive by way of comparison. No. 1 is from the semi-assoited glacio-lacustrine clays that border Lake Michigan, the specimen being from Milwaukee, Wis. No. 2 is from a glacial pebbly clay beneath the glacio-lacustrine clays at Milwaukee.

Analyses of glacial clays.

No. 1.		No. 2.	
	Per cent.		*Per cent.*
SiO_2	40.22	SiO_2	48.81
Al_2O_3	8.47	Al_2O_3	7.54
P_2O_5	.05	P_2O_5	.13
TiO_2	.35	TiO_2	.45
Fe_2O_3	2.83	Fe_2O_3	2.53
FeO	.48	FeO	.65
MnO	Trace	MnO	.03
CaO	15.65	CaO	11.83
MgO	7.80	MgO	7.05
K_2O	2.36	K_2O	2.60
Na_2O	.84	Na_2O	.92
H_2O	*a*1.95	H_2O	*a*2.02
CO_2	18.76	CO_2	15.47
C (organic)	.32	C (organic)	.38
SO_3	.13	SO_3	.05
	100.21		100.46

a Contains H of organic matter. Dried at 100° C.

Rock relics.— Cherts are present wherever chert-bearing limestone was one of the rocks which has disappeared in the progress of decomposition. They are abundant or rare according as the decomposed rock contained much or little flinty material. In size the chert masses vary from small particles to pieces one or two feet in diameter. They vary widely in color, as they are seen to do in the rock, being white, gray, yellow, and red, with all intermediate shades. They are frequently scattered throughout the earthy product, but are much more abundant at the base of the clay than higher up.

Below the mantle of residuary clay and above the firm rock, there is everywhere a layer of semi-decomposed rock. This varies widely in thickness and physical characters. Above, the cherts are more or less intermingled with the clay, and are, in descending order, replaced by semi-decomposed fragments of the country rock, which quickly predominate and exclude the clay, and, graduating below into solid rock, complete the section of residuary material.

In some places the amount of rock remnants is small. In such cases they are composed of small fragments which do not appear to have any definite arrangement. They are commonly soft and friable, as a result of decomposition, and are intermingled with varying but always small amounts of clay. In other places the passage from the clay through the intermediate layers of mingled clay and rock fragments, and the deeper-lying layer of rock fragments almost without clay, to the firm strata beneath, is gradual, and only accomplished in the space of several feet. In such cases, if the topography be plane, the semi-decomposed rock fragments often preserve the stratified arrangement proper to the layers from whose destruction they have resulted. The stratification is distinct and regular, wherever the underlying corroded sur-

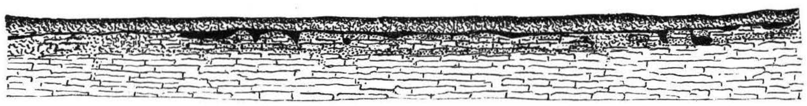


FIG. 43.— Section showing partially decomposed rock below a thin layer of very dark clay. (Near Mount Horeb, Dane County, Wisconsin.)

face is regular. Where this has become notably uneven by unequal decomposition, the overlying layers of decomposed fragments have conformed themselves measurably to the irregularities beneath. Where the irregularity is great, the stratification has become obscure or altogether obliterated. Wherever the surface is plane, the rock fragments uniformly lie on their flat sides, indicating the absence of the action of all disturbing forces since their formation. Wherever the topographic situation is other than that indicated, the rock fragments are irregularly distributed, or at least their disposition bears no definite relationship to the bedding of the underlying rock.

Large masses of limestone, or even masses two or three feet in diameter, are exceedingly rare in the ordinary sections of residuary material in the area under discussion. Along ravines leading down from steep slopes, and particularly at their bases, such pieces of limestone, and even larger ones, occur. These have been loosened from their original position by disintegration, and have been transported to their present positions by gravity or by the violent torrents which flow down from the slopes after every heavy rainfall. These masses are not, however, in any proper sense of the term, bowlders of decomposition. They have been separated by decomposition, following in the wake of cleavage, but they are rarely rounded or even deangulated—characteristics which are diagnostic of bowlders. Furthermore, the rock masses, even where they occur in considerable size, are rarely of firm texture. Oxidation, solution, and, consequently, incipient degradation have usually penetrated to their very cores, so that the amount of loose material from which bowlders could be made by any forcible agency is small. It is probable that bowlderets, cobble stones, and pebbles might, in some moderate measure, have resulted from the subjection of the loosened rock to the proper processes, but that the measure would be limited is attested by the general absence of such products in the valleys of the region, where cherts have accumulated in great quantities. That the limestone does not occur in such situations is proof of its incompetency to withstand the agencies of transportation, for there can be no doubt that the quantity of limestone that started down the valleys much exceeded the amount of chert, as the former is much more abundant than the latter on the highlands and slopes. It is our judgment, therefore, so far as inference can be drawn from the driftless area alone, that the origin of the limestone bowlders of the drift must be, in the main, sought elsewhere than in the pre-glacially disintegrated limestone masses.

Below the outer border of the drift in Central Missouri, observations have been made which do not perfectly tally with those already noted. Large masses of limestone have there been frequently seen imbedded in clay and completely separated from the layers of rock. These are sometimes of large size, even eight to ten feet in greatest diameter. Their surfaces, so far as seen, are, as in the driftless area, exceedingly irregular.

Beneath the partially disintegrated rock, there are loosened masses of considerable size, which are still in situ, and adjacent, both laterally and below, to solid rock. These, when removed and subjected to glacial action, might be productive of bowlders in large numbers, but such masses do not come under what we have termed decomposed rock.

Except where the covering of clay is thin, pieces of residuary limestone are almost unknown at the surface. Chert, on the other hand, is to be found superficially in some regions, even where the clay is deep, in great abundance. This is perhaps most common in the horizon of the Lower Magnesian limestone, in which flint masses are more abundant than elsewhere and of larger size. In a few places in Wisconsin, and, much more conspicuously south of the drift limit, in Missouri, the cherts and silicious residuum of the decomposed rock are excessively abundant on sloping surfaces. Where thickly imbedded in the tenacious clay, as they frequently are, they form a protection to the underlying clay, which is thus allowed to accumulate to depths much greater than those proper to like topographic situations elsewhere. This protecting superficial stratum sometimes attains a depth of several feet, being fully one-half chert.

In some situations the limestone beneath the clay, instead of breaking up into pieces which retain their horizontal position, passes through a different form of decomposition, whereby the upper surface becomes sandy. The transition from the rock to clay under such circumstances is much more abrupt than is common elsewhere. The sand has no constant depth, but, besides forming a thin covering over the rock surface, it often fills the small pockets and crevices which penetrate the uppermost layers of rock. This is always highly calcareous and appears to be made up in considerable part of crystalline dolomitic particles.

In the sandstone regions the relation of superficial earth to decomposed rock beneath is quite similar to that indicated for limestone regions. The fragmentary rock is less resistant and the rock surface proper less clearly defined. There are less commonly accumulations of rocky material at the base of slopes, but, on the other hand, bowlder-like forms—we would not, however, term them bowlders of decomposition—are not unknown. They are often very unique in form and peculiar in structure. They have generally very smooth surfaces, and cross sections show the central portion to have the general appearance of tolerably pure silicious sandstone. Surrounding the friable core, is a coating of varying thickness in which the normal sandstone texture is obscured or destroyed, apparently by the complete filling of the intergranular spaces and the attendant dimming of the grain outlines. The outer surfaces have thus assumed the texture of quartzite,[1] while the inner portion is still porous sandstone. These masses are rarely round, though never angular unless freshly fractured. They are sometimes long and more or less regularly cylindrical, but more frequently oval, oblong, or curved. Their occasional external resemblance to the more or less regularly cylindrical ferruginous concretionary forms found in adjacent regions, where the compact portion is ferruginous and similarly surrounds a core of sand, often uncompacted, suggests a community of origin. In the sandstone region, where the rock is firm, apart from these bowlders, rock masses are more common than in limestone belts.

Bowlders of exfoliation are abundant at the surface in the regions where quartzite is the underlying rock. While the rock masses are here more often than otherwise angular, subangular and even rounded forms are not infrequent. There is generally less decomposed rock

[1] Bulletin United States Geological Survey, No. 8, on Secondary Enlargements of Mineral Fragments in Certain Rocks, by R. D. Irving and C. R. Van Hise.

beneath the clay in these localities than in the regions of Paleozoic rocks.

Amount of residuary material.—The depth of residuary material has been ascertained in nearly eighteen hundred localities in the driftless area. In the larger percentage of cases the data upon which the results here given are based are the result of direct personal measurements. The other data were secured by whatever means possible, e. g., the records of borings, diggings, and all kinds of excavations. The data are drawn from all portions of the driftless area and from all topographic situations, and may, therefore, be taken to represent, with a fair degree of accuracy, the average amount of material which mantles the region. A minor element of inaccuracy, or at least of uncertainty, inheres in some cases where it was not ascertained whether the recorded depths included the disintegrating rock as well as the earth or whether they embraced only the earths. This however can hardly lead to serious error, since the number of such uncertain measurements is not great.

The following general averages are based on measurements which include the residuary earths and that portion of the residuary rock which is intermingled with them, but which do not include the disintegrating rock which underlies the clay but is not commingled with it. The average depth of residuary material, thus defined, as shown by the eighteen hundred measurements, is 7.08 feet. The amount varies widely in different topographic situations. It is greater on ridges and in valleys than on slopes, and is deeper the wider the ridges and the valleys. Of about one thousand measurements on slopes, steep and gentle, the average depth is 4.61 feet. On ridges, not including broad tracts of upland, the average, as shown by three hundred and sixty measurements, is 8.06 feet. Two hundred and nineteen measurements on broad upland tracts give an average of 13.55 feet. The average for broad ravine bottoms, or short, wide valleys unoccupied by streams, is 6.93 feet, as indicated by one hundred and twenty-three measurements. The average of fifty-five valley measurements is 18.17 feet. In this last class are included only the measurements made in valleys which have a notable flat, and the average here given may not very well represent the average depth of loose material in such situations, since measurements in the large valleys, as those of the Mississippi, Wisconsin, and Pecatonica Rivers, were rarely obtainable, but would have served to swell the average result. The extremes of depth are zero on the one hand and 70 feet on the other, the maximum being on upland. It is not certain that in this instance the excavation was not in a crevice. Measurements exceeding 25 feet are, in this topographic situation, exceedingly rare.

The amount of superficial clay, including loam, but not including the sand beneath it, is somewhat less in regions where sandstone is the underlying rock than where limestone takes its place. The amount of residuary rock, on the other hand, is greater in the sandstone tracts, and so much greater that the total residuary product is in excess of that in the limestone belts. In the limestone regions it is ascertained on the basis of measurements that the amount of residuary rock, including all that is thoroughly loosened, is from one and three-quarters to two and one-quarter feet, with a maximum of six or seven feet. This is not to be interpreted as meaning that two feet of residuary rock is to be added to the seven feet already given as the average depth of the residuary earths, since, as already indicated, that average included a considerable proportion of the residuary rock. The amount of residuary rock to be added to that estimate would at most not exceed one and one-half feet. In sandstone belts the rock surface is much less clearly defined, so that the amount of residuary rock is less readily determined, but its amount is two or three times as great as in the limestone belts.

The amount of residuary material thus indicated is in sharp contrast with the depth of loose material which overlies the rock in the surrounding drift-bearing region. Measurements at hand in Green County, Wisconsin, give the following results: (1) In the drift region, but adjacent to its border, involving an area nowhere more than 10 miles from the border, the average of seventy-two measurements of superficial material, as obtained from wells and other excavations, is 16.8 feet (with variations from two to fifty-three feet), while the average of an equal number of measurements across the drift border in the driftless tract, likewise involving an area only a few miles from the drift limit, is only 7.9 feet (with variations between four and twenty feet). It should be here noted that the drift border at this point is the border of the older drift, and, while it is reasonably distinct, it is not marked by any morainic or other noticeable accumulation at its edge, so that the difference in amount of superficial material is much less than where the drift limit is marked by the massive moraine of the second ice epoch.

The drift clays are notably calcareous. Whence came this element? It is manifest that the data already given furnish a basis for determining what would be the composition of drift if it were simply residuary material reworked and intermingled. The clays may be said to contain no appreciable calcareous material. Taking the average amount of residuary rock in limestone regions as two feet, it is easy to calculate how large a calcareous ingredient this could impart to the residuary product as a whole.

Assuming that the residuary rock is pure dolomite, the resulting product, if it were intermingled with the clay above, would yield about 22 per cent. of dolomitic material. This is much less than the drift actually contains, rock fragments being included in the estimate. Furthermore, it is manifest that certain deductions should have been made in the above computation, and that the intermixed residuum, even in limestone belts, would contain a much lower percentage of dolomitic material. For, in the first place, of the residuary rock, a not inconsiderable part is chert. It is estimated that this forms not far from one-fourth to one-fifth of the residuary rock. Again, the disintegrated dolomite has quite certainly suffered a reduction of the percentage of its dolomitic material, since this is what was first removed in the process of disintegration; indeed, it was this removal which constituted the disintegration, so that the latter is, in some sense, the measure of the former. The more completely the rock is decomposed, therefore, the less must be its percentage of dolomitic material and the greater its proportion of impurities, especially silica and silicates.

If proper allowance be made for these considerations, it would probably reduce the percentage of dolomitic material nearly one-half. We estimate that it would be above rather than below the truth to place it at 15 per cent. of the total residuum embraced in the preceding measurements.

It is further to be kept in mind that this estimate is based upon the residuary material of the limestone districts alone. It is manifest that if this were commingled with the residuary material from sandstone and crystalline areas, whence little or no calcic or magnesic carbonate could be derived, the total percentage of these ingredients which the drift would contain, if this were their only source, would be again reduced. This reduction would be in proportion to the relative areas of limestone and non-calcareous rock over which the drift forces acted.

It seems to us, therefore, demonstrable that the products of secular decomposition are an incompetent source of the drift in general, though they made a notable contribution to the earlier glacial deposits. In the later, they played but an insignificant part. It seems to us not improbable that the total amount of material lost by wash during the ice age was greater than the whole of the residuary material.

Rock surface.— A moment's attention to the surface of the rock below the residuary products will be of service for comparison with that presented beneath the drift mantle of the adjacent region. The limestones, particularly the rough-textured beds of the Lower Magnesian, Galena, and Niagara formations, present an exceedingly rough, rotten surface. Disintegration has proceeded with more or less irregularity, and decay has eaten the surface into pits and canals. Decomposition has descended along the main crevices to great depths, very commonly a half a hundred feet, and not infrequently much more. For considerable distances below

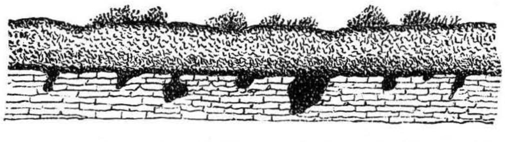


FIG. 44.— Section showing the formation of chimneys by irregular decay of surface. Very dark clay next the rock. Railway cut, east of Cobb, Iowa County, Wisconsin.

the general rock surface deep "chimneys," as they are termed by the miners, penetrate the beds, while lesser forms of the irregular disintegration appear continually throughout the rock in various directions.

These features stand in striking contrast to the smooth-surfaced rock presented where glacial planation has been effective. In the sandstone areas the rock surface is still more indefinite, owing to the less coherent nature of the rock.

FIG. 45.—A representative profile of the southern portion of the driftless area.

This substratum of weakened, partially loosened rock offered material easily disrupted and removed by glacial action, while much of it was, at core, sufficiently resistant to form bowlders. In the earlier glacial action this, together with the true residual material, constituted the chief local contribution to the drift.

Capacity of the valleys, and its relation to the amount of residuary material.—We have previously called attention to the capacity of the immediate valleys of the Mississippi and Wisconsin Rivers. It was estimated that to fill the trench of the Mississippi, excluding entirely lateral valleys and its broad basin, and confining attention merely to the interbluff gorge, would require a layer to be taken from the entire surface of the driftless area of the thickness of about 25 feet. Estimating in the same way, we found that a layer about 8½ feet thick would have to be cut from the entire surface of the driftless area to fill the immediate chasm of the Wisconsin River. It is somewhat difficult to arrive at a satisfactory estimate of the total capacity of the valleys of the region. After having given the subject considerable attention in the field, we have arrived at the general impression that in the southern half of the district the capacity of the valleys is less than the cubic contents of the ridges; that is, if the whole were graded to a common slope, the plain so formed would lie nearer the crests of the region than the bottoms of the valleys. On the other hand, we have formed the impression that in the northern half of the district the reverse would be true; that, if the surface were reduced to a common plane, it would lie nearer the bottom of the valleys than the crest of the hills. Averaging the whole region, it appears to us that the capacities of the hills and of the valleys are very nearly equal, and that to produce a uniform plain having the same slope as the great rivers it would be necessary to cut down the heights half their altitude.

Stating the question in terms of drift, it is roughly estimated that, to fill up the valleys so as to produce a surface similar to the average heavy drift surface of the adjoining States, an average thickness of drift of about 150 to 200 feet would be required, all the summits of the ridges being still left bare. To bury the whole region in drift so as to leave rock exposures as infrequent as they are in the heavy drift regions of the four adjoining States would probably require at least an average thickness of 300 feet.

Stating the problem in terms of residuary material, it is estimated that, if all the decomposed material upon the uplands and slopes were removed from the entire driftless region into the trench of the Mississippi adjacent, it would fill it about one-third the way up. If it were all removed into the part of the Wisconsin trench within the area, it would barely fill it to the tops of its bluffs. If the entire residuary material of the region were removed from the hills into the adjacent ravines and valleys, it would scarcely produce an appreciable modification in the contour of the region. When considered with reference to its ability to fill up the valleys of the eroded surface, the amount of residuary material is absolutely trivial.

The bearings which these facts have upon the estimation of the amount of drift and the method of action of the drift agencies are manifest. If the driftless region is a true index of the pre-glacial conditions of the surrounding region, it is obvious that either the hills were extensively truncated, and the material thus derived used to fill the valley, or that there was a very large importation of foreign material, and the total amount of drift must be great.

It is probable that some of the adjacent regions now occupied by drift plains were not originally so uneven as the average of the driftless area. But there seems to be no good reason for doubting that other portions had nearly equal relief.

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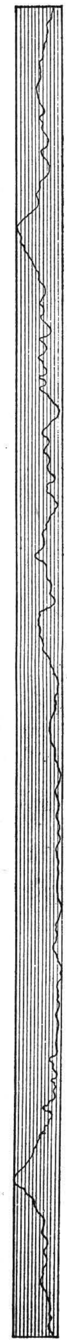


FIG. 45.—A representative profile of the southern portion of the driftless area.

we have specially to consider here was the product of the Green Bay glacier, a tongue-like lobe of the great northern mer de glace. This tongue pushed down through the Green Bay Valley, deploying to the right and left as it protruded southwestward. It seems to have actually encroached in some measure upon the area which had previously been driftless, so that a segment, reaching from Dane County to Waushara County, lapped upon the driftless territory and formed a new border of drift hills strikingly in contrast with the older attenuated margin. The course of this moraine along the border of the driftless region and in the adjacent territory may be best understood by reference to the accompanying map. The terminal curve of the Green Bay ice lobe, at the time it was forming this moraine, lay athwart the Rock River Valley in Rock County, in Southern Wisconsin. Tracing this to the westward, it is found to strike the driftless region in the southwestern quarter of Dane County, and there, entirely overlapping and passing beyond the old drift sheet, it forms the new morainic border. It curves gradually more and more to the north through Dane and Sauk Counties, and then gently recurves to the east of north, and in Waushara County leaves the driftless region and passes off upon the old drift territory, and throughout its further course does not again come in contact with the territory under consideration.

The vicinage of this terminal moraine affords fine contrasts between the characteristics of driftless and drift-bearing regions. Approaching it from the driftless tract, we travel over rolling country, every rod of which shows the impress of subaërial erosion and over every acre of which are spread residuary earths unmixed with glacial erratics. At the border of the drift, sharp ridges are suddenly encountered, together with knolls, peaks, kettle holes, indented surfaces, and contorted, if not distorted, valleys, the whole forming a combination utterly impossible of formation by drainage sculpture. Over the surface are scattered in profusion erratics representing nearly all the formations that lie within a range of 500 miles northeast. Crystalline and clastic rocks are commingled in inextricable confusion. Turning to the substratum where laid open by natural or artificial agencies, instead of the rock core, which in the driftless region uniformly lies beneath the shallow mantle of residuary earth, we find the morainic hills often wholly composed of heterogeneous till. Sections of 30 and 40 feet of drift are occasionally displayed among the outermost ridges, with clear indications that the part laid open is far from being the whole. The total depth of drift is unknown, but is probably not less than 300 feet at some points along the margin.

Standing on the border line, along the face of the moraine, no observer can fail to be impressed with the verity of the contrast in the phenomena presented, nor with its extreme significance. On the one side there is a perfect drainage system; on the other, drainage is incomplete and considerable areas have no external drainage at all. On the one hand is a region everywhere betraying the impress of drainage sculpture; on the other, a region which drainage sculpture is absolutely incompetent to produce. On the one hand the drainage lines are symmetrical; every least ravine fitly joins its neighbor ravine, and their confluent valley joins another of like origin, leading on and on to other unions until the whole system has gathered into the great drainage arteries of the region. Not an acre is without its appropriate portion of the drainage system, save an occasional solution pit, or an abandoned channel on the bottoms, or an inter-dune depression. On the other hand, the drainage lines are distorted into irregular and anomalous forms; the valleys are gnarled and twisted, blocked by ridges, or anon expanded into flats and marshes or lakes, or otherwise deformed in the most irregular and unsymmetrical fashion. On the one hand are intelligibly arranged ridges, betraying the hand of nature's symmetrical sculpture; on the other, ridges bunched in the most irregular forms, setting at defiance all laws of symmetry and orderly arrangement. There is the contour-beauty of symmetry set over against the even more unique beauty of asymmetry. On the one hand are rolling hills, with smooth erosion contours or with mural faces outjutting along their steep sides; on the other, a sea of confused drift hills. On the one side is a thin mantle of residuary material; on the other, a thick, corrugated sheet of heterogeneous drift. On the one side is only local material, the simple result of universal terrestrial agencies; on the other, an inextricable mixture of local, semi-local, and foreign material, the extraordinary results of phenomenal causes. The one region is bowlderless, while over the other are strewn in great abundance erratics from distant regions. On the one hand the rock surface below the residuary mantle is of an irregular, rotten, half-decomposed character; on the other hand it is usually denuded of its decomposed material, its asperities are reduced, and its surface is polished and striated in that unique fashion which is the distinctive work of glaciers.

The fringing deposits of glacial waters.—Outside the moraine lie two classes of deposits which gathered apace with it. The precipitation which fell upon the western slope of the glacial lobe, together with the water which arose from the same part of the glacier by melting, was shed from the edge, except the portion that may have found exit beneath in other directions and the portion lost by evaporation. Copious streams were doubtless the result. It is not difficult to understand that these, as they issued from the glacier, should have been exceptionally charged with silt, sand, and rolling stone, and that, as turbid waters, they poured down the channel-ways that were open to them. Long trains of glacial wash stretching away from the edge of the ice and leading down the several valleys testify to the reality of such streams.

The most notable flood-train originating on the actual border of the driftless region is that which stretches down the valley of the Wisconsin River. The edge of the ice lobe crossed the Wisconsin in the western part of Dane and Sauk Counties. In the immediate valley of the river the moraine is largely composed of gravelly constituents, disposed in kame-like hills and ridges, or undulatory and pitted plains, showing the combined action of wash and push on the part of the glacier and its waters. Originating from this gravelly moraine, there stretches away a flood-train of gravel and sand, reaching down the valley to the Mississippi, and, there joining similar gravel streams originating higher up, it continues down through the driftless area and beyond, though only remnants now remain. This valley drift originates at a height of about 90 feet above the present level of the Wisconsin River, and as it stretches down the valley gradually declines, so that, as it leaves the driftless region, it is barely 50 feet above the Mississippi. Near its origin coarse cobbles, bowlderets, and even occasional bowlders are not infrequent. Farther down, the material becomes finer, and, in the lower stretches, only pebbles and sand are found. The lessening coarseness of the deposit seems to show that as the glacial waters issued from the edge of the ice they were overloaded and struggling with a burden too great for their complete mastery; and, while they successfully carried the silt, sand, and even some of the finer gravel far down their courses, the heavier material in large part lodged near its origin and progressively filled the bottom of the channel.

This phenomenon, of which the Wisconsin Valley presents the only complete example lying entirely within the driftless region, finds other examples in several streams which cross the region. The Black River, the Chippewa, the Mississippi, and the Zumbro are all attended by such glacial flood deposits, which may be traced back to their origin on the face of the outer moraine. All these glacial flood plains slope more rapidly than the present streams. The train in the Chippewa Valley falls a little more than six feet per mile in the first 40 miles of its course, and over five feet per mile from its source on the face of the moraine to the Mississippi. In crossing the driftless area the glacial flood plain of the Mississippi declines about 50 feet more than the present stream.

The fringing deposits of ponded waters.—It is manifest that a broad glacier moving out upon an area carved into an intricate system of valleys must necessarily have obstructed a portion of them, and, so far as it was competent to do so, must have ponded back their drainage and poured into them its own also, forming marginal lakelets, in which would be deposited the wash from the surrounding land and the sediment which the turbid glacial waters bore into them. The moraine is fringed with such deposits. For the most part they are limited in extent. A fine example is found in the valley of the Baraboo River. The ice movement from the east occupied the valley to a point a little above Baraboo, and there threw up its terminal ridges athwart the valley; so that both ice and morainic débris contributed to dam back the stream. The result was the deposit throughout the valley of a stratum of silt of very considerable thickness. It would appear from present evidence—not yet demonstrative, however—that the waters were ponded back until they were able to overflow into the plains of Juneau County, over a low intervening col.

A much more extensive and impressive example was caused by the obstruction of the Wisconsin River itself. It appears highly probable that before the glacial period the Wisconsin River, after pursuing a course in its upper portion not greatly different from its present one, crossed the Baraboo ranges in Sauk County by the gap in the range now occupied by the Baraboo River, and known as the Lower Narrows, and through the gap in which Devil's Lake now lies.[1] This latter is a picturesque cañon 400 to 475 feet deep at the locality of the lake. The configuration is such as to leave little doubt that the original cañon was at least 600 or 700 feet deep. This is now blocked by a stout moraine to a probable depth of 300 to 400 feet. The occupancy of these gorges by the ice and morainic débris cut off the drainage of the greater portion of the Wisconsin basin from its accustomed outlet. Not only that, but the slopes of the adjacent glaciers presumably discharged an unwonted amount of water into the upper basin. The result appears to have been the accumulation of a somewhat extensive lake, occupying the plains of parts of Adams, Juneau, Wood, and Jackson Counties, which had been previously reduced essentially to a base level of erosion, as previously described. Without rising to very considerable height, this lake found an easy discharge into the valley of the Black River and thence downward to the Mississippi. It resulted in spreading over those plains a sheet of sand and silt and in developing that smooth surface expression that now characterizes them.

FIG. 46.—Old gorge of the Wisconsin River through the Baraboo quartzite ranges; blocked by moraine, shown in center of cut. Devil's Lake, entrapped between morainic ridges, in the foreground. Bluffs 400 to 475 feet high. Ancient gorge probably filled with drift 300 to 400 feet.

[1] Irving, Geology of Wisconsin, Vol. II, 1877, p. 508.

ATTENUATED TILL-AND-BOWLDER BORDER.

We have already seen that the Kettle moraine swings away from the border of the driftless region, both at the north and at the south, and leaves outside of itself a portion of the older drift-sheet, which was not overridden by the ice of the later epoch. It is the margin of this older drift sheet which now claims our attention. If evidence is desired that this drift is much older than the moraine, it may be found in several lines of testimony. The very fact that it lies outside of the Kettle moraine—that is, beyond the extent to which the moraine-forming ice-sheet reached—is sufficient indication that it is older under the accepted view that it is of glacier origin. This, however, does not of itself indicate that there is any notable difference between the ages of the two. The moraine might be conceived to mark merely an oscillation in the retreat of the ice. Additional evidence is required to prove distinct diversity of age.

Beneath the overwash gravels that fringe the moraine in the Rock River Valley there are considerable accumulations of vegetable material. The wells of Johnstown, Rock County, sunk at various times during the last thirty years, have frequently penetrated these. The maximum depth of material charged with vegetal remains is several feet.[1] The time requisite for the accumulation of this vegetable matter, while somewhat considerable, was not, geologically speaking, necessarily prolonged. Such deposits have, however, been regarded as proving distinct difference of age.

A surer indication of notably greater age, in our judgment, is to be found in the very much more marked surface modification of the older drift. The contours of the moraine and of the later drift sheet within the moraine are notably fresher. As previously indicated, drainage has not yet had time to fully establish itself. Numerous sinks and marshes remain as yet undrained. Numerous indentures of hills and irregular contours resulting from the impact of the ice remain not only unobliterated, but in many instances almost unsubdued. On the contrary, the drift outside the moraine presents universally softened contours, with nearly or quite perfected drainage systems, and a configuration which, while more gentle than that of the driftless region, yet approaches it in its conformity to the laws of drainage sculpture. These features are not easily expressible in definite terms, but they appeal to the experienced eye with a force not to be escaped or misunderstood.

Of like import with the subduing of the surface by drainage is the deep oxidation of material and the advanced stage of disintegration of the pebbles and bowlders. It is a very notable fact that disintegrated pebbles and bowlders are very much more common in this older sheet of drift than in that within the moraine. In some instances a large percentage of such constituents as are susceptible of ready disintegra-

[1] From information furnished by Rev. Mr. Reynolds, of Johnstown.

tion have suffered marked decay. Some allowance is undoubtedly to be made for the original condition of the drift material. The earliest ice incursion acted upon the disintegrated surface of rock of pre-glacial times, and scraped from it material which undoubtedly contained a larger percentage that was already undergoing decomposition than did that of the later incursions, which acted upon a surface from which these partially decayed materials had already been pushed away. We have made efforts in the field to discriminate between material which was probably already partially disintegrated when taken up by the ice and that which underwent decomposition subsequent to its deposition. While fully appreciating the difficulties of such a discrimination and the doubts that must attach to results, we yet think that some measure of success has been attained, and we feel confident that a very considerable percentage of the amount of decay presented by the material of the older drift is due to decomposition which took place subsequent to its deposition.

Moreover, while decomposition has been in progress, the opposite process of cementation has likewise been active. Many of the old gravel deposits have been quite extensively solidified. This solidification has been accomplished variously by calcareous, ferruginous, or silicious cement. While this is a very common phenomenon in the gravel banks of the older drift, it is far less frequent in the gravel hills of the moraine and the region within. This difference is most notable in the induration due to ferric oxide. Ferruginous secondary conglomerates are by no means common in the newer drift, while they are measurably frequent in the old.

In further support of these evidences, we shall endeavor to show presently that the attitude of the surface was quite different in the periods marked by the two deposits.

Since a general change of conditions involves time in its production, an evidence of diversity of age may be found in the very facts which we are describing, namely, the differences in the character of the drift border.

Nature of the border.—There is a very significant contrast between the margin of the older drift sheet[1] and the morainic border of the newer drift, which we have previously described. There is a total absence of the thickened ridge border that so sharply delimits the latter. Even a keen observer fails to note the point of passage from the drift-bearing to the driftless region, unless his attention is studiously directed to the subject. Even then he will be able to determine the exact limit only by a vigilant outlook for erratics. In general, the drift terminates in this way: Approaching the edge from the drift side, the till becomes

[1] We do not here wish to assert or imply any final opinion as to whether this older sheet is the oldest of the drift sheets known to us in the interior or not. We do, however, desire to be understood as holding that this belongs to one of the two or more ancient drift sheets, as distinguished from the two or more later drift sheets whose margins are marked by the great moraines of the interior.

gradually thinner and discontinuous, until, at length, it disappears in an irregular patchy border. The bowlders and pebbles, meanwhile, have had a wider range than the till, and are usually scattered more or less freely over the patches where no bowlder clay remains. These stony elements usually extend beyond the limit of the bowldery clay a short distance. In some places bowlders of moderate and occasionally considerable size (two to four feet in diameter) form the extreme limit of detectible drift. In others bowlderets and pebbles constitute the extreme margin. Bowlder clay, however, sometimes lies within half a mile of the extreme border.

The bowldery clay is sometimes of the true glacial type up to within a mile of the border, being composed of a calcareous clay matrix of that physical aspect that indicates a mechanical origin, in which are imbedded glaciated stones, some of which are derived from the adjacent formations, some from more distant ones lying at various points backward to 300 miles, showing that the glacier which produced the deposits must have gathered its material at various points along the line of glacial movement for 300 miles or more backward. But on the immediate border this typical glacial till is largely replaced by a mixture in which residuary clay and slightly modified rock fragments are prevalent, in other words, residuary surface material rewrought and mingled with a moderate contribution of foreign material. But even in these deposits the clay matrix usually gives prompt effervescence on the application of acid, indicating that it is not simply residuary clay. Striated pebbles are not uncommon in this, but are not so abundant as in the previous class. The bowlders of the extreme border are not usually glaciated, but some of them have contours that give the impression that they have suffered glacial reduction. Many of them, however, indicate a glacial origin only by their rounded forms and firm outlines. Their rounded forms might, to be sure, have been attained by decomposition and exfoliation, but their clean, smooth faces are manifestly not the products of decomposition, but of some form of abrasion, and their sizes and contours point to glacial attrition. Nevertheless they do not bear in themselves conspicuous evidences of glacial action, and may have been borne mainly within the basal body of the ice rather than pushed along its bottom.

Beds of assorted and stratified material are relatively rare along the margin, another feature of contrast to the adjacent morainic border, in which the products of wash are impressive features. At occasional points there are beds of gravel and sand associated with bowldery clay or replacing it. Only in a few instances are there accumulations of the kame type near the edge, though these are not infrequent at some distance back from it. Some instructive examples of these are found in the vicinity of Monroe, Wis.

These are not independent hillocks but are embossments on the slopes of rock ridges. They consist of assorted material stratified in oblique, discordant, and to some extent disturbed attitudes, and, in three instances, were found overlaid by a few feet of calcareous till charged with glaciated stones. As topographical features, however, they are quite insignificant and would arrest the attention of only the most experienced observer. They are, nevertheless, very significant features, since they indicate important conditions. A part are set on slopes facing westerly toward the driftless region, a part on easterly slopes, and all lie below the summit level of surrounding hills. The little knolls in the western part of the city of Monroe appear to be almost entirely composed of drift gravel, but were too ill exposed to admit of satisfactory observation. About $1\frac{1}{2}$ miles southeast of the city three large pits have been opened upon these deposits. Two of these show depths of about 20 feet and the other about 15 feet. Though differing among themselves, they all present a like general phenomenon. The upper portion is composed of till whose matrix is a calcareous clay. In this are imbedded a plentiful supply of glaciated pebbles of limestone; in part from the adjacent Galena formation and in part from compact white Niagara limestone, whose nearest appearance in situ is at least 60 miles to the eastward. There is also embraced a considerable percentage of various crystalline pebbles and bowlders, reaching up to two feet in diameter. About three-fourths of these are Archean, the remainder being limestone, chiefly of the two kinds indicated. Notwithstanding the fact that these bowlders have been imbedded in clay, they present a notable degree of disintegration. Not a few of them were broken squarely across in the progress of developing the pits, while others were in a crumbling condition. It appears manifest to us that a considerable portion of this disintegration must have taken place since they were deposited, because they are now too fragile to withstand the vicissitudes of transportation for the 300 or more miles which they must have traveled from their original home. Furthermore, the exteriors often show a polishing of which they would not now be susceptible. The calcareous character of this till and the numerous finely glaciated pebbles within it deserve especial note. Below this stratum of till, at the three localities alike, lie from 10 to 15 feet of glacial gravel and sand, of various degrees of fineness, which, for the most part, has been well assorted and deposited in oblique and cross laminations. In a few instances, manifest disturbances took place after the first deposition, and the relations of the till to the gravel became involved in the disturbance. At one point, a neat little illustration of minor faulting occurs which would appear to have been contemporaneous with the original deposition. The sand is nearly everywhere calcareous and clean limestone pebbles form a large element of the gravel, though chert is its most abundant constituent. Immediately beneath the gravel comes a rotten-surfaced limestone or a residuary clay. But not enough was seen of the bed of the pits to justify any general statement.

These facts, though they fall much short of setting forth the full phenomena, sufficiently indicate that at the time of the formation of these deposits there must have been a discharge of waters capable of assorting the material and reducing to roundness a portion of the drift. This took place in advance of the agency which spread over them the stratum of till. The large percentage of glaciated material in this till and its calcareous character seem to us clearly to indicate its subglacial transportation, and, as the gravel is of essentially the same constitution, we regard it as a derivative from the same source as the till, but deposited in advance of that special portion of the till that overlies it. The topographic situations in which these deposits are found are such as to forbid their explanation on any glacio-natant hypothesis, if, indeed, the very constitution of the deposits themselves does not entirely negative such a view. We appear to have an instance here of deposits of assorted drift carried forward by glacial waters in advance of the ice or else deposited under its margin in cavernous arches, the deposits being subsequently overridden by the advancing ice and buried beneath a layer of till.

A part of the attenuation of the old drift border is doubtless due to erosion subsequent to the time of its formation, but we have been unable to find any evidence that the border ever consisted of any special aggregation of drift to which we would apply the name terminal moraine. On the contrary, the drift mantle seems to us to have originally thinned out gradually to an attenuated edge. It is scarcely possible that the Kettle moraine, or any other of the pronounced terminal moraines, could be reduced by erosion to the phase which the old border presents.

Course of the border of the old drift.—As previously observed, the moraine forms the concave east side of the driftless quadrilateral. The border of the old drift, which we have now under consideration, forms the two adjacent sides, namely, the short southeastern side between Dane County, Wisconsin, and Savanna, on the Mississippi, in Carroll County, Illinois, and the northern concave border stretching from the Wisconsin River westward to the Chippewa Valley.

On the southeastern side the old drift emerges from beneath the moraine in Vernon Township, Dane County, Wis. Its course thence is southwesterly to the vicinity of Savanna, on the Mississippi River. In general, the line is nearly direct, but in detail it undulates to and fro to the amount of three miles. The course is over hills and valleys quite irrespective of the special topography. The advances and recessions of the marginal line appear to correspond to topographical features lying back from the margin, to which the sinuosities are perhaps due.

In southern Jo Daviess and Carroll Counties, Illinois, as the Mississippi is approached, the border of the drift is overlain by a thin mantle of loess, which stretches back from the Mississippi and covers a portion of the otherwise driftless region and a portion of the drift border.

On the north, the emergence of the old drift sheet from the later one is not so definitely determinable on account of the sand plains and marshes which prevail in the basin of the Wisconsin. Some of these sand flats are overwash products of the glacial floods of the later epoch. The plains appear to have been occupied by waters ponded back by the obstruction at the Baraboo ranges, as heretofore described. The presence of these ponded waters seems to have given a wide distribution to the sands and silts of the glacial wash, and these contributed to bury the surface and render the tracing of the earlier drift margin difficult and uncertain. The marshes that prevail at certain points contribute their share to increase the difficulty. Aside from these unfavorable conditions, the limit of dispersion, where it is traceable, gives reason to think that the border was even more attenuated than in the more rolling region above described. But the precise quarter section to which it reaches is immaterial, except that it would be serviceable to know its exact course at the junction, since that might give us a hint as to what was the outline of the driftless region before it was encroached upon by the later glacier, which pushed its moraine out upon it. So far as we can gather from the data at command, the amount of this encroachment was but slight.

With the qualifications which these elements of uncertainty impose, it may be said, as representing our best knowledge, that the border of the old drift which disappears beneath the moraine in southern Dane County emerges again in Portage County. Thence its course is westerly, curving gently to the north, to the Chippewa Valley, passing through Wood, Jackson, Clark, Trempealeau, and Eau Claire Counties. The slight curvature which it presents indicates a gentle lobation of the ice as it crept down the southern slope of the Wisconsin highlands.

Throughout the larger portion of this course, the border lies upon a smooth, gentle, southerly-sloping plain which is almost without relief in the eastern portion. On this plain the drift is attenuated to more than its usual degree, and the margin consists only of scattered erratics, sparsely distributed on the extreme edge. Traced back, these thicken and become mingled with a thin mantle of bowlder clay which only attains a considerable depth at points distant from the margin. In the Chippewa Valley, the drift border becomes involved in a complexity of formations which may be best considered a little later. The immediate valley of the Chippewa and its larger tributaries, the Eau Claire and the Red Cedar, are widely filled with an immense stream of glacial flood deposits derived from the Chippewa lobe of the glacier of the later epoch. These flood deposits conceal all earlier ones that lie within the immediate valley, and the backwater deposits, caused by the silting up of the main streams, in like manner bury whatever may occur in the minor tributaries. In the vicinity of the Mississippi an attenuated mantle of loess stretches out over drift and driftless areas alike and partially conceals the earlier formations. But the most serious difficulty in exact delimitation arises from the exceedingly attenuated distribution of the pebbly border, presently to be described. The further consideration of this border will therefore be resumed in that connection.

It is only the northern and the southeastern sides of the driftless quadrilateral that belong exclusively to the till-and-bowlder border, the eastern concave side being morainic and the long convex western side having an attenuated pebbly border.

Absence of valley drift.—We have noted as a conspicuous fact that there stretch away from the morainic border trains of valley drift, formed by glacial drainage. It is especially noteworthy that no such trains have been found as appendages of the earlier drift sheet. This is a most singular and, we think, most significant fact. So far as present topography is concerned, there is no essential difference between the later border in Dane and Sauk Counties, where gravel trains stretch away from the moraine, and the older border in Dane and Green Counties, Wisconsin, and Jo Daviess and Carroll Counties, Illinois, where trains are not found. This latter border lies upon rolling country, and there lead away from it valleys of notable size, which we should naturally expect would have drawn very considerable drainage floods from the margin of the ice. Valley trains having escaped notice in the earlier observations of the region, the subject received special attention in our later studies, with almost entirely negative results. Nowhere have we found satisfactory evidence of the existence of such valley trains. Only in one instance have we found drift gravel in such a valley, and in that instance the deposit was a fine gravel mixed with sand situated beneath the present flood plain and not in the form of a shoulder or manifest remnant of an old train. Our examinations have not been completely exhaustive, and we have not yet entirely dismissed the view that remnants may yet be found to exist; but our observations upon the exterior of the older drift at various points between Ohio and Dakota have revealed a similar condition of things there, when we have eliminated those valley trains which are referable to the later glacial stages. Whatever may be the result of the future intended search for such deposits, our observations at present are sufficient, we think, to certainly forecast two results. It will be found (1) that such deposits were never formed in quantities comparable to those of the later epoch, and (2) that denudation since has been sufficient to remove almost or quite completely such deposits as did accumulate. It seems well nigh impossible to frame a satisfactory conception of the conditions then prevalent which would not necessitate the deposition either of coarse or of fine sediments in these border-draining valleys. Still, if the ice of the earlier epoch were relatively thin near its margin—and there are independent reasons for thinking it was so—it would probably be more influenced by subjacent topography than if thicker, and would be more extensively crevassed. This would provide a way by which superficial streams would be transferred to the bottom of the glacier before reaching the margin, and they would then doubtless be led away beneath the ice by streams which found exit mainly through the great arteries of drainage, instead of the numerous small ones along the margin of the ice. If this were true, it would be natural to suppose that these main valleys would be all the more filled with drainage material, unless it lodged beneath the ice. But we have not discovered this to be true.

If the general slope of the surface were lower, there would have been a less prompt withdrawal of the glacial waters and their transporting power would have been reduced. This would aid us in accounting for the absence of coarse gravelly material, such as constitutes a large element in the valley trains of the later epoch; but this lower gradient would have facilitated the deposition of a finer grade of material, the sands and silts with which the glacial waters must have been abundantly supplied. It is perhaps possible to conceive, for a given locality, an intermediate balancing of conditions which was unfavorable to the transportation of the coarser material, but yet furnished slope enough to enable the waters to carry away the finer suspended silt, so that only a relatively limited *intermediate* grade of fine sand was enabled to find lodgment in the valleys. It seems difficult, however, to imagine that such a balance of conditions should have been very widely prevalent when we consider the varying gradients of the valleys now affected by the phenomenon. It is not, however, irrational to suppose that conditions may have prevailed which prevented the deposition of any considerable gravelly material at the one extreme or fine tenacious clay at the other, and which favored a moderate deposition of the lighter sands and silts, which, being readily erodable, disappeared during the long interglacial epoch which we have other reasons for believing intervened between the later and earlier main epochs. Whatever may be the true explanation, the phenomenon remains a pregnant one and constitutes a discriminative criterion of great value.

ATTENUATED PEBBLE-DRIFT BORDER.

The contrast between the attenuated till-and-bowlder border and the morainic border is carried into still further antithesis by the attenuated pebble-drift border. The limitation of the last is as vague as that of the moraine is bold. The characteristics of the one are as indecisive as those of the other are pronounced. Starting from the center of the driftless region and going eastward we abruptly encounter the moraine; starting from the same point and going westward we first find, by diligent watchfulness, an occasional well-rounded foreign pebble. Farther on, pebbles increase in frequency and size. Still farther on, there appears a thin stony-clay bed, in favorable localities, having a matrix scarcely distinguishable from the residuary clay of the region, in which are mingled pebbles of foreign origin, together with cherts and other local material common to the residuary mantle. Further progress in this direction develops a more general distribution of this formation over the surface and an increasing thickness as well as increasing size of included erratics. Still farther on, this merges into one of the older drift sheets of Iowa and Minnesota. The width of this attenuated tract of drift reaches 30 miles, though it is usually less than that amount. (See Plate XXVII.)

The character and distribution of the pebbles are very peculiar. On the extreme border they consist almost exclusively of small well-rounded pebbles of white quartz. Usually these are few and scattered and are found mixed with local angular cherts and residuary clay, presenting a combination as singular as it is trivial. The quartzose pebbles are not usually very different from such as might be formed by selection from the silicious nodules of the local limestones, and for a time there seemed reason to think they were merely local. A grave objection to this view, however, lay in the fact that they were so thoroughly rounded and reduced to small size, while the local material with which they were associated betrayed no evidence of modification. Furthermore, as observations became more numerous, there appeared among the round, white, quartzose pebbles not uncommon instances of deep-red, jaspery ones. Now, while there are red flints in abundance among the residuary products derived from the limestone, they very rarely assume the jaspery hue of these pebbles, which is indistinguishable from that of the Huronian jaspers of Lake Superior. Further search, especially along lines leading westward toward the heavier stratum of drift, brought to light occasional instances of banded jaspery hematites, to which nothing similar is found in the local series. So, also, there occasionally appeared a pebble of one of the greenstones of manifestly foreign derivation. Then, also, but more rarely, a pebble of granite or of porphyry was found. With these undoubted erratics, the white, quartzose pebbles were found mingled more abundantly than near the border, where their origin seemed problematic. Passing westward toward the body of the drift, these several ingredients increase in number and in size, the red, jaspery pebbles become more frequent, and the greenstones increase with greater relative rapidity, if our numerous observations are truly representative, and other classes of pebbles mingle more freely. As the border of continuous drift is neared and this pebbly deposit becomes more nearly universal in its distribution, the lithologic range of pebbles becomes greater.

There may be ground for suspecting an intermixture of pebbles representing the two drift members of the adjoining region. An average of the several analyses which we made at different points in Iowa, Minnesota, and Wisconsin gives the following assortment: Of the greenstone class, 46 per cent.; of quartzites and jaspers, 19 per cent.; of white and light colored quartz, 12.3 per cent.; of the granitic class, 18 per cent.; of hematites, 2.25 per cent.; of porphyries, 2.3 per cent.; unclassified, .15 of 1 per cent. Under the term "greenstone" we group, for convenience, a variety of augitic and hornblendic rocks, both massive and schistose. It is impracticable in the field to identify great numbers of pebbles with sufficient accuracy to classify trustworthily by lithologic species. It is also impracticable, in many instances, to determine the precise formation from which they were individually derived. There are pebbles of the greenstone class that might be derived from either the Keweenawan, Huronian, or Laurentian series, or from rocks intruded into these. We entertain little doubt that the majority were derived from the Keweenawan and Huronian formations of the Lake Superior region, notwithstanding the possibility of derivation in part from the Laurentian series. The jaspery pebbles and hematites are distinctively of the Huronian type. The granitic pebbles we refer with little hesitation to the Laurentian Series, though a few may be derivatives from intrusions in the Huronian and Keweenawan series. The small, light-colored quartzose pebbles have a less certain source, but we incline to the belief that the most of them came from the conglomerates of the Cretaceous series, coinciding in this with a suggestion previously made by Prof. N. H. Winchell.[1] Reckoning the greenstones, quartzites, jaspers, hematites, and porphyries as Huronian and Keweenawan, the granites, gneisses, syenites, &c., as Laurentian, and all the quartz pebbles as Cretaceous, the results are as follows: Huronian and Keweenawan, 69.55 per cent.; Laurentian, 18 per cent.; and Cretaceous, 12.3 per cent.

On the border of the pebbly tract nothing like a definite layer of foreign material is developed. Farther back the semblance of such a layer is preserved in favorable localities. It consists of a stony-clay mixture, the erratics of which are usually well-rounded pebbles and but rarely glaciated. These are imbedded in a clay that very closely resembles the residuary clay of the region and embraces considerable quantities of angular chert and other local rock fragments. It would be practically impossible to distinguish this clay from the residuary clay of the region, in the majority of cases, were it not for the intermixture of the foreign pebbles and a small ingredient of sand. There is, however, an occasional instance of stratification and of slight assortment, which is not common in the residuary mantle. This stratum is rarely more than three or four feet in thickness. Sometimes this semi-foreign mantle lies directly upon the rock surface, there being below it no intervening stratum of residuary earth. The rock surface in these instances is almost universally decayed and rotten, of a type almost precisely like that of the driftless region. In other instances there lies below the stratum containing foreign pebbles a bed of typical residuary earth containing only cherts and other local rock fragments. In most instances there is but an indistinct demarkation between the two, but in

[1] Geological and Natural History Survey of Minnesota, Vol. I, 1872–'82, p. 309.

some instances it is well defined. At some points there are slight indications of stratification, but in the majority of instances the appearance is as though, in some inscrutable way, a few foreign pebbles had become inserted in the residuary mantle common to the region. The amount of pebbles so inserted is usually not large and they are usually small and inconspicuous, so that the presence of anything other than the common mantle of residuary material would not arrest attention, except by the character of the pebbles.

This stratum is by no means universal, but has a patchy, irregular distribution. Many miles may be traveled without observing instances of foreign material, though every hill-slope is laid open by gullies. Then the observer may turn back on a parallel line, similarly situated with reference to the general distribution of formations, and find foreign material present on every hillside.

It is extremely difficult, if not impossible, to trace this formation in complete, unconcealed continuity westward until it merges into one of the drift sheets that overlie the adjacent parts of Minnesota and Iowa, and thus determine by exact stratigraphical demonstration its equivalent. This was not assiduously attempted by us, as it lay beyond our special field. From our own observations, we could not say that both members of the earlier drift may not be accompanied by an attenuated fringe — a view which we understand Mr. McGee to hold. But the foregoing characteristics incline us to regard the limital fringe which we studied as the equivalent of the lowermost member of the series described by Mr. McGee.[1] In this latter, greenstone erratics greatly predominate and are imbedded in reddish and yellowish residuary-like clays embracing numerous flints and other fragments of local derivation. The thickness of the series is likewise trivial. The upper stony deposit described by Mr. McGee is characterized by a preponderance of granitic erratics.[2] This corresponds with Professor Winchell's description of the erratics of the superficial bowldery stratum of Southeastern Minnesota. In our own observations we have observed a striking transition in the character of the erratics when we have passed from this attenuated greenstone pebbly drift westward to the area overspread by the continuous sheet of drift, the superficial member of which we, like our predecessors have found to be rich in granitic erratics. We therefore provisionally regard this attenuated edge of drift as the vanishing border of the lowermost member of the drift recognized in Northeastern Iowa, Southeastern Minnesota, and Northwestern Wisconsin.

Concerning the question whether its attenuated character was original or was acquired through erosion, we incline strongly to the former opinion. There has undoubtedly been very considerable erosion since it was spread out. Its discontinuous character is probably mainly due

[1] On the Complete Series of Superficial Geological Formations in Northeastern Iowa. Proc. Am. Assoc. Adv. Sci., Vol. XXVII, August, 1878.

[2] Loc. cit.

to this. But it seems to us quite impossible that such erosion could have removed the heavier, coarse erratics from the margin and have left only the fine, well-rounded ones, which, a priori, we should suppose would be first carried away by denuding agencies. It seems plain to us that, though much worn, tattered, and frayed by erosion, the margin was originally what we now find it, an attenuated tract of pebbly drift, shading out gradually, until it vanished in a scarcely determinable edge.

Distribution.— The edge, being of this almost indeterminable kind, is difficult to map with precision. The pebbles are distributed in their discontinuous way over the entire region west of the Mississippi, with the possible exception of the extreme northeastern corner of Iowa and southeastern corner of Minnesota. In common with preceding observers, we have not actually observed foreign pebbles in the northeastern townships of Alamakee County, Iowa, nor in any except the southwesternmost township of Houston County, Minn., except in the valley deposits along the Mississippi, which manifestly belong to another category. It would be quite rash, however, to say that they may not occur here. Across the Mississippi, at two points immediately opposite the drift-barren corners of Iowa and Minnesota, drift pebbles have been found. About four miles east of De Soto, Vernon County, Wis., a single pebble of purple quartz-porphyry, together with pebbles of quartz and quartzite, was observed. This was unquestionably drift, and its association with the quartz and quartzite fragments would indicate that all may have had the same origin. Southeastward from La Crosse, we found localities where not only white quartzose pebbles were present, but also those of jasper and of banded hematitic ore, for which we know of no assignable origin except the Archean iron-bearing formations of the north. A few pebbles have been found in the vicinity of Galena at altitudes above the apparent reach of the floods of the later glacial epoch. These, while they might have been transported by human means, are probably members of this formation. In Grant County, Wis., we failed to find any erratic pebbles on the heights, but we still suspect their occasional occurrence.

In Crawford County, high on the divide between the Kickapoo and the Mississippi, there occurs, at Seneca, a very singular accumulation of quartzose pebbles embraced in a ferruginous matrix, forming a concentrated local deposit described by the late Moses Strong.[1] This not only lies upon the surface, but extends down a fissure to a depth of 65 feet, to which extent it was penetrated by a mining shaft. The material excavated was essentially a ferruginous gravel, the pebbles being almost universally white smoothly-rounded quartz. This has every appearance of being a local deposit, quite unconnected with the drift, no undoubted pieces of which were found. The occurrence here still throws some doubt upon the view that the white quartz pebbles are of distant origin. It may be that this is a remnant of a Cre-

[1] Geology of Wisconsin, Vol. IV, 1875–'79, p. 88.

taceous conglomerate that once extended thus far east and here became inserted in a gaping crevice of the magnesian limestone. The degradation of such a stratum might leave its quartzose pebbles quite widely distributed over the region, mingled among the residuary products of the subjacent limestone. One of us detected a grain of granite in a sandy clay deposit near this locality, whose character was sufficiently different from the usual residuary earths to attract attention. Independently of this question we should regard this as of drift origin, particularly as the loess mantles the same region. It is not material, however, to our present purpose to decide this question, since it would only affect by a few miles the eastward extent of unquestioned erratics.

Beyond the Trempealeau River, as noted some years ago by Mr. Strong,[1] occasional patches of gravelly drift occur on the heights east of the Mississippi. We have verified and added to the instances of such occurrences. It would be an error, however, to imagine these to be gravel deposits in the ordinary acceptation of the term. In most cases that have fallen within our observation, the deposit is merely a mingling of these erratic pebbles with locally-derived flints, forming a thin, somewhat concentrated stratum at the base of the subsoil or of the loess-like loam of the region. Such occurrences extend along the east side of the Mississippi as far as the Chippewa Valley, beyond which, in Pepin County, bowldery drift occupies the surface. Nowhere on the east side of the Mississippi between the northeastern corner of Illinois and the Chippewa River, a distance of 150 miles, have we been able to find drift more than five or six miles back from the Mississippi, except in a few instances of single pebbles that were not clearly in situ. These last are most probably instances of human transportation. In the several thousand well-exposed sections which we have examined we have been able to find no drift of any kind so imbedded as to give any reason to believe that it was a natural deposit.

The western border of the driftless region is therefore closely approximate to the Mississippi River, lying immediately east of it from the Chippewa River to the Trempealeau, perhaps then swinging over it to the west, cutting across the cognate corners of Minnesota and Iowa,[2] and striking the river below; it remains essentially coincident with it to the Illinois line, where it swings eastward far enough to include the vicinity of Galena and the river-bordering hills below.

In its topographic distribution, it is worthy of note that the pebbly erratics are not confined to valleys leading down from the drift sheet on the west, as though they were valley streams issuing from the drift region. Nor are they merely distributed over eastward slopes, as though they were washed down from the west at a time when the topographic configuration was more favorable to such action than now. They are

[1] Geology of Wisconsin, Vol. IV., 1873–'79, p. 92.

[2] We have followed the negative results of observation, but we presume more complete search would show that the border lies east of the river here also, as is indicated by the drift pebbles of Vernon and La Crosse Counties, already noted.

scattered so indifferently over the various inequalities of surface that any hypothesis of transportation by wash is negatived. The fact that they were carried across the deep trench of the Mississippi is in itself almost decisive, for it is incredible that the valley could have been excavated since the deposit was made and any remnant of the latter be left. On the east side of the Mississippi pebbles occur at heights of 400 feet and more above it. On the west side they appear in valleys, on slopes, and on crests, being scattered over undulations which have a vertical range of 700 feet. To suppose these reliefs of surface to have been carved out since the erratics were scattered over the region, without their removal, is quite unwarrantable. An erosion which could have differentiated such a surface must have entirely removed a stratum of drift had it been many times as important and as massive as we have any reason to suppose this was. Besides, the remnants of such an erosion could hardly have taken the precise form which this deposit presents, as indicated above and below.

Method of deposit.— Coming more specifically to the question of method of deposit, we remark again that there frequently lies below the attenuated pebble drift undisturbed and unmodified residuary clay, embracing unmodified flint fragments and also possessing other characteristics demonstrative of its complete integrity. At other points where the residuary material was entirely removed, the rock surface is still of the ragged, rotten character common to unglaciated regions. There is nowhere any distinctive evidence of glacial planation, nor are there the other characteristic indices of glacier deposition. This, taken together with the peculiarities of the marginal distribution, viewed in the light of the topography of the region, which is almost identical with that of the driftless district, seems to exclude a belief in the occupancy of this tract by a glacier.

We naturally turn to the agency of water-borne ice. To account for it under this hypothesis, it is necessary to believe that the region west of the Mississippi, reaching back to varying distances up to 30 miles, was submerged, while that to the eastward was not, at least as a general and persistent fact, except immediately along the Mississippi, for the eastern drift border has no such pebbly extension. But the western margin of this region rises over 700 feet above the Mississippi, while most of the driftless region east of it does not exceed that altitude, much of it lying from 100 to 300 feet lower. To account for the facts of distribution, it would therefore seem necessary to suppose that there was a relative depression upon the westerly side. This is especially necessary if it be true that this western pebbly formation is the equivalent of the old drift on the eastern and northern sides, which seems to us most probable, since both are overlain alike by the loess deposits, which probably were contemporaneous with the second stage of the first glacial epoch. But we shall have occasion to recur to this question of westerly depression in connection with the loess and will not further consider it here.

CHAPTER IV.

THE LOESS.

DIFFERENTIAL CHARACTERS.

Typical loess is neither a sand nor a clay, but a silt of intermediate fineness. It is finer and more uniform than sand and less fine than clays and residuary earths, though the latter are generally less homogeneous and their constituents have a wider range in size. The loess is conspicuously coarser than the residuary earths, if we may judge from the fact that, after the particles of the latter have been thoroughly separated from one another and the ultimate physical elements caused to be freely suspended in water, a much longer time is required for the settling of the particles than is the case with loess when subjected to the same treatment.[1] The statement sometimes made that loess will never completely settle would be much more conspicuously true of the residuary earths. When equal amounts of loess and clay, *after complete disaggregation*, were placed in equal amounts of water and allowed to stand under the same conditions, the amount of loess remaining in suspension at the end of four hours was not greater than the amount of residuary earth remaining in suspension at the end of thirty-six hours, estimated on the basis of turbidity. The exact time required for the settling of all the particles, or whether all will ever settle under the ordinary conditions, has not been determined. It is certain that in each case some particles will remain in suspension for long periods of time, if there be even slight jarring or gentle disturbance from currents of air or changes of temperature. But the practical question with which we are dealing is not the settling of the ultimate particles, but the subsidence of the body of the material. A certain percentage of the finest particles is entrapped in any subaqueous deposit, even the coarsest. This incidental ingredient increases as the conditions become more favorable for the deposition of fine particles, and, in deposits of silt intermediate between sand and clay, naturally becomes larger and should be regarded in the same light as interstitial sand is in studying the depositional conditions of a gravel bed. To attempt to estimate the flotation of silts and clays by the time requisite for the settling of the last suspended

[1] It is only when complete disaggregation of the clays is effected that the power of water to hold it in suspension is best exhibited. A semi-reduction of the material, easily effected and easily mistaken for complete reduction, would show quite different results. It seems to be the rule that the finer the particles the more tenaciously do they cohere and consequently become the more difficult to separate.

particles may not be unlike determinations of the suspension of gravel in currents by agitating a quantity and noting the time of complete clarification from incidental earth. The elaborate and valuable experiments of Brewer and others on the subsidence of lingering turbidity relate to a grade of particles much below that which we regard as typical loess, and we find in them little direct light on its deposition.

Measurements have been made of over 150,000 particles of loess, or loess-like loam, from the driftless area and immediately adjacent to it. It should be kept in mind that in this region the loess graduates imperceptibly into the residuary earths which it borders, and that true loess particles and particles of residuary earth are actually intermixed, if our views concerning the origin of the loess be correct. The loess loam of these localities, therefore, might be expected to be somewhat finer than typical loess, not only by virtue of the intermixture, but also because the loess mantle is very thin and post-loessial disintegration has had opportunity, more completely than where the loess is thicker, to accomplish further reduction. The first series selected for measurement and study were from divers localities in and adjacent to the driftless area, and from both sides of the Mississippi. The results are as follows: Of 150,887 particles, 146,894, or about 97⅓ per cent., fall under $.005^{mm}$ in diameter, leaving only 2⅔ per cent. of greater size. It will be remembered that, of the residuary earth measurements, about 99.9 per cent. of the particles had a diameter less than $.005^{mm}$. The comparison in this form, however, does not express the full difference between the two kinds of material, for the average size of the loess-loam particles which fall below $.005^{mm}$ is much greater than the average size of the residuary earth particles which fall below the same limit. The number of exceedingly minute particles in the loess is, indeed, great, but the relative number which approach $.005^{mm}$ in diameter is vastly greater than the number of like size in the residuary earth.

Of the 2⅔ per cent. which exceed $.005^{mm}$ in diameter nearly one-third exceed $.0114^{mm}$. Of these, few reach a diameter of $.025^{mm}$. It is significant that the largest particles are almost uniformly flat, many of them being mica scales. The extreme size noted was $.1139^{mm}$ by $.0285^{mm}$.

Samples of typical loess from Kansas City and Vicksburg have been examined for the purpose of comparison. Of 87,135 particles from Kansas City, about 4 per cent. measured over $.0025^{mm}$ in diameter, and a little more than 1 per cent. above $.005^{mm}$. They range up to $.1^{mm}$, and particles above $.05^{mm}$ are not rare. Of 57,401 particles from Vicksburg, 1.7 per cent. measured over $.0025^{mm}$, and 1 per cent. over $.005^{mm}$. These range up to $.075^{mm}$, and are not rare up to $.035^{mm}$. Combining results, of the total 144,536 a little more than 3 per cent. measured above $.0025^{mm}$ in diameter, and about 1 per cent. above $.005^{mm}$. The 96 per cent. of finer material from Kansas City was observably coarser than the 98.3 per cent. of fine particles from Vicksburg.

Samples of loess from the Rhine, collected by J. E. Wolf and furnished by Mr. J. S. Diller, were also examined for purposes of comparison. Of 23,937 particles measured, 85 per cent. were found less than .0025^{mm}, 11.25 per cent. between .0025^{mm} and .005^{mm}, 3.05 per cent. between .005^{mm} and .01^{mm}, and .7 of 1 per cent. over .01^{mm} and ranging up to .2^{mm}. Among the minerals microscopically detected were quartz, orthoclase and plagioclase feldspars, biotite and muscovite micas, hornblende, and magnetite.

In glacial clays the inferior limit in size is low, as low as in loess, but the range upward is indefinite. The examination of a few samples of finely assorted red clay (Champlain) of the Lake Michigan region indicates a fineness of constituents comparable to that of the residuary clays, but the studies in this line have been quite limited. It is certain, however, that this deposit is composed of particles whose average size is much less than that of the loess particles.

The fineness of the residuary earths, and, less conspicuously, of the loess, can be realized best by comparison with sand. It is difficult to define with anything like precision the limits of fine sand, but a sand whose particles range from .05^{mm} to .12^{mm} in diameter would be universally considered fine. The particle .05^{mm} in diameter would, if disintegrated without loss of substance, make 15,625 particles .002^{mm} in diameter, a common size in residuary earths. A grain .1^{mm} in diameter would, in like manner, yield 1,000,000 whose diameter would be .001^{mm}, a size equal to that of probably one-half the particles of residuary earths.

A prominent characteristic of the loess, a characteristic which it shares with the residuary earths, is the angularity and irregularity of its particles. In typical loess a well-rounded smooth grain has not been seen. Sharp corners and rough surfaces are the rule and any approach to regularity or smoothness the exception. Opaque grains are more common in the loess than in the residuary materials, resembling in this particular glacial clays, in which the proportion of opaque particles is still larger.

It is a common assertion that loess possesses great uniformity of texture. In a general sense this is true. In a special sense it is quite far from being true, even in typical loess. In the Kansas City loess the proportion of particles which exceed in diameter .0025^{mm} is about 14 per cent.; in the Vicksburg loess, not quite 1.7 per cent. While a general inspection of the deposits makes it probable that these are not the average proportions of coarse and fine particles in the Kansas City and the Vicksburg loess, respectively, this does not militate against the point here urged, viz, the diversity of the loess, for the above proportions are deduced from actual measurements, and therefore establish the fact of diversity at the two places, at least in the layers from which the specimens were taken. It would probably be quite accurate to say that the loess is homogeneous in any given stratum at any given locality. It is a formation in which assortment has reached a high degree of perfection, but the assortment in all localities and under all conditions is not the same, and hence different strata vary in their grades of coarseness and fineness. In different situations the loess is found to vary, but within moderate limits. The product at a given point is relatively homogeneous. We find the loess in the vicinity of the Mississippi River (and the same is true of that near the Missouri, Platte, and other great rivers) of coarser grain than at points removed from it. In the river bluffs it sometimes merges into and becomes interstratified with layers that are a fine sand rather than a loess, some of them being typical sands serviceable for mortar. On the other hand, as the formation is traced towards its limit in the driftless region, it approaches more and more closely in character the residuary clays, seeming to be a mixture of true loess silt of foreign derivation and a varying percentage of local residuary earth. On its western margin, however, next the driftless area of Iowa, Mr. McGee describes it as coarser and grading into fine sand in the centers of the peculiar varieties of osars that lie along its margin.

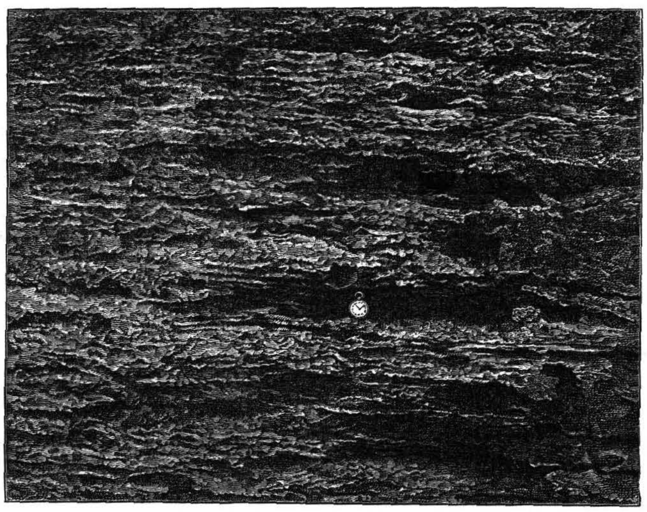


FIG. 47.—Stratification of the loess in a railway cut at Plattsmouth, Nebr., at a depth of 84 feet from surface. From photograph furnished by Dr. A. L. Child, of Kansas City.

Chemical and mineralogical constitution.—Four representative analyses of loess have been made for us by Mr. Riggs, the results of which are given in the tables below. No. 1 was taken from the summit of a ridge in the suburbs of Dubuque, Iowa, at a point about three hundred feet above the Mississippi River. No. 2 represents a 7-foot stratum of loess, lying over brown residuary clay, near Galena, Ill., at about three hundred and fifty feet above the Mississippi River. No. 3, from Kansas City, Mo., was chosen as representative of the most pronounced loessial characters at that locality. No. 4 was taken from near the center of Vicksburg, Miss., at about two hundred feet above the Mississippi River, and probably fairly represents the upper half of the stratum there, but we think not the lower portion, which seemed heterogeneous.

Table of analyses of loess.

No. 1.—Dubuque, Iowa.		No. 2.—Galena, Ill.		No. 3.—Kansas City, Mo.		No. 4.—Vicksburg, Miss.	
SiO_2	72.68	SiO_2	64.61	SiO_2	74.46	SiO_2	60.69
Al_2O_3	12.03	Al_2O_3	10.64	Al_2O_3	12.26	Al_2O_3	7.95
Fe_2O_3	3.53	Fe_2O_3	2.61	Fe_2O_3	3.25	Fe_2O_3	2.61
FeO	.96	FeO	.51	FeO	.12	FeO	.67
TiO_2	.72	TiO_2	.40	TiO_2	.14	TiO_2	.52
P_2O_5	.23	P_2O_5	.06	P_2O_5	.09	P_2O_5	.13
MnO	.06	MnO	.05	MnO	.02	MnO	.12
CaO	1.59	CaO	5.41	CaO	1.69	CaO	8.96
MgO	1.11	MgO	3.69	MgO	1.12	MgO	4.56
Na_2O	1.68	Na_2O	1.35	Na_2O	1.43	Na_2O	1.17
K_2O	2.13	K_2O	2.06	K_2O	1.83	K_2O	1.08
H_2O	*a*2.50	H_2O	*a*2.05	H_2O	*a*2.70	H_2O	*a*1.14
CO_2	.39	CO_2	6.31	CO_2	.49	CO_2	9.63
SO_3	.51	SO_3	.11	SO_3	.06	SO_3	.12
C	.09	C	.13	C	.12	C	.19
	100.21		99.99		99.78		99.54

a Contains H of organic matter. Dried at 100° C.

Besides these approximately complete analyses a considerable number of partial determinations and many hundred simple acid tests in the field and under the microscope have been made, so that, though the number of full analyses is not large, they merit some confidence, particularly as they tally so well with the microscopic determinations of the constituent mineral particles. As indicated in the discussion of the residual earths, there have been detected, besides the preponderating quartz, particles of orthoclase and plagioclase feldspars, biotite and muscovite micas, hornblende, augite, magnetite, dolomite, and calcite. The chemical analyses become full of significance in the light of these determinations. The amount of water may be taken as roughly indicating, when allowance is made for the hydration of the iron oxide, the quantity of kaolinized products. The average of these four analyses, after such allowance, is considerably less than 2 per cent., while that of the four analyses of residuary earths is more than 7½ per cent. More significant perhaps is the ratio of water to alumina, as indicating the extent of decomposition and hydration of the original silicates. In the loess and glacial clays it is so small as to indicate that the silicates have not become completely decomposed and hydrated, while in the residuary clays it is so large as to imply very full hydration. The suggestion of these facts is that the loess and glacial clays were produced in part by mechanical abrasion or crushing. The presence of dolomitic particles is of like import.

By inspection of the analyses it may be seen that it is possible to construct a very plausible mineralogical interpretation in perfect harmony with this view and with the microscopical observations; but, as it is our purpose to reach a mineralogical analysis of these silts by more direct and positive methods, this may well be deferred.

Distribution.—The accompanying map (Plate XXVII) shows the distribution of the loess so far as immediately related to the driftless area. It will be observed that its eastern limit lies on the east side of the Mississippi River and that thence it stretches westward to the drift area of Iowa and Minnesota. There are two significant belts along which it is thickest. One of these lies along the Mississippi, the other along the western border of the loess, on the margin of the continuous drift in Minnesota and Iowa. In the immediate vicinity of the Mississippi it is usually thicker than at points removed a few miles on either hand. On the east it is not thick even in the vicinity of the Mississippi, rarely exceeding a depth of 15 feet and averaging, perhaps, less than 10, even where it is well preserved. From this thickness it rapidly thins to the eastward, and rarely appears in its distinct characters at more than 10 miles from the brink of the river valley. Beyond this there may be found patches of superficial loam, neither typical loess nor typical residual earth, but possibly a mixture of the two. Still beyond are the superficial earths in which a few microscopic grains of magnetite, hornblende, feldspar, mica, and other seemingly foreign minerals are found, as previously stated in the discussion of the residuary earths.

On the west side of the river the loess likewise thins for ten or twelve miles, and then gradually thickens toward its limit on the west.

If some difficulty was encountered in readily fixing the precise limitation of the attenuated pebbly drift, much more was presented in the delimitation of the loess upon the east side of the Mississippi. In the former instance, the difficulty lay mainly in the labor of search necessary to confidence regarding the extreme extent to which the scattered pebbles are distributed, and, subordinately, in the interpretation of the white quartz pebbles; but in the latter case the chief difficulty lies in the fact that the border becomes modified so as to be scarcely distinguishable from certain phases of the residuary earths. This arises from two sources. The superficial portion of the loess has everywhere been affected by meteoric agencies and has become transformed into soil. The distinction between this soil and that which is derived from the residuary clays, while usually discernible, is not characterized by sufficiently sharp distinctions to be always satisfactorily discriminated. This transformation into soil affects the formation to a depth of from three to five feet, and occasionally somewhat more, so that when the loess becomes thinned to this amount its entire body has been transformed into soil, and no typical loess remains. In the second place, as already indicated, the border became modified by the introduction of residuary material; in other words, it appears to have originally been formed in part of true loess material and in part of wash from the residuary soil of the surrounding country. The difficulty is further increased by the fact that wash from the residuary soil of the summits has produced very similar accumulations upon the slopes and in some of the valleys, wholly independent of the loess. Æolian and animate agencies have been believed to occasion similar surface accumulations. When, therefore, the loess mantle becomes thin and has been eroded so that only patches remain, it is extremely difficult to decide, in individual instances, whether these are modified remnants of the loess mantle or merely secondary accumulations of residuary soil. The map presents the limit to which we have traced, with any degree of confidence, the distribution of this thin modified formation. It appears to us to be approximately the extent to which any notable thickness of it originally overspread the region. Whether the microscopic foreign minerals found mixed with the apparent residuary clays over the greater part of the region are to be interpreted as an extension of the attenuated edge of the loess, or are to be attributed to wind dispersion or to casual submersion at an earlier stage of glaciation, when the region was surrounded by ice, through the occasional blocking of the drainage outlet, is as yet to us uncertain. There is certainly no appreciable mantle on the eastern half corresponding to that on the western border.

On the west side of the Mississippi River, loess seems to have originally prevailed everywhere back to the border of the continuous drift. Since its deposition, however, it has been extensively worn away from the valleys and often from the hill tops. It is most frequently exposed on the upper brows of the hill slopes, where gullies, starting on the crown of the ridge, trench its brow as they pass over it. The loess usually occupies the crown of the ridge and reaches down to the steep portion of the brow. Here the erosion has usually cut away the loess and exposed the drift or residuary clay beneath. Farther down, where the brow verges into the foot-slopes, rock often appears.

Along the border of the heavier drift westward, the loess is again thicker and more universally present. Here the loess mantle passes out upon the continuous drift sheet, as long since observed by Winchell[1] and McGee.[2] According to the latter, it overlaps the upper as well as the lower till of the region, but only reaches westward a short distance beyond the margin of the former, so that it may be regarded

[1] Reports of the Geology and Natural History Survey of Minnesota, passim.

[2] "On the Complete Series of Superficial Geological Formations in Northeastern Iowa." Proceedings of the American Association for the Advancement of Science, August, 1878, pp. 4, 5.

"The Drainage System and the Distribution of the Loess of Eastern Iowa." Bulletin Philosophical Society of Washington, Vol. VI, November 10, 1883.

Messrs. Winchell and McGee have kindly furnished data for outlining on the accompanying map the western border of the loess in Minnesota and in Iowa, respectively.

as nearly, but not actually, conterminous with the upper till of the earlier epoch. In Northwestern Illinois we have traced the loess sheet back from the Mississippi continuously, and have found it spreading out upon the drift of that region, reaching eastward upon it to a considerable, but as yet not definitely determined, distance. Farther south it extends continuously from the Mississippi across to the Illinois River. We have assured ourselves by reconnaissance that loess is continuous in the vicinity of the Mississippi, save as dissevered by erosion, from the driftless region southward to at least the central latitudes of Illinois, beyond which, current authorities are unanimous respecting its continuity to the vicinity of the Gulf. There may be distinctions of age or of origin, which, from their obscure nature, escaped our detection, as our studies beyond the drift border were only reconnaissances, but at present we incline to think that a contemporaneous belt stretches from the vicinity of Lake Pepin to Louisiana. We hold this without prejudice to the presumption that there may be tracts of other loess occupying parts of the same territory.

On the northern side of the driftless region there are occasional thin deposits of loess-like loam overlying the thin margin of the drift or spreading over adjacent portions of the driftless region. These deposits appear to be identical in nature and coincident in time with the loess of the Mississippi. Examples occur south of the Eau Claire River as far east as Augusta. Even as far down as Elroy, accumulations that seem to be of the same nature occur. These, however, do not attain any great thickness or notable prevalence.

Later fluvial loess.— Along some of the tributaries of the Mississippi River there are loess-like deposits, which are to be distinguished from the general mantle above described. These are confined to the immediate valleys of the present streams and are limited to altitudes less than 100 feet above them, mainly less than 50 feet. They are usually much more definitely stratified than the general loess mantle and more commonly intercalated with layers of sand and clay. They constitute terraces along the tributaries of the Mississippi which are continuous with the gravel terraces of the great valley and have at their junction the same heights. This relationship and their manifest later origin, as shown by the relatively slight erosion they have suffered, make it very clear that they are deposits formed contemporaneously with the filling of the main valley by the glacial flood deposits of the later epoch. The filling of these tributaries is merely a secondary deposit, derived from the older and parent loess by wash and redeposited in the slack water developed in the tributaries by the silting up of the main stream.

Fossils.— Leaving out of consideration this later and secondary valley loess, the formation is not rich in fossil shells. At Savanna, Ill., at its southernmost point, we found the following, which have been determined by Prof. R. E. Call: *Patula striatella*, Anthony; *Patula striogosa*, Gould; *Succinea avara*, Say; *Succinea obliqua*, Say. In the southwest quarter of section 26, Bloomington, Grant County, Wis., *Succinea avara*, Say. At Galena, Ill., 135 feet above the Galena River, *Succinea avara*, Say; *Succinea obliqua*, Say; and *Helicodiscus lineatus*, Anthony. East of Prairie du Chien, on the heights at 425 feet above the Mississippi, *Succinea avara*, Say; and *Limnophysa humilis*, Say.

Among the later secondary loess deposits, the following have been found: In the terraces at Galena, *Succinea avara*, Say; *Succinea obliqua*, Say; *Lymnophysa humilis*, Say; *Vertigo simplex*, Gould; *Patula striatella*, Anthony, and *Gyraulus parvus*. In the higher terraces at Bridgeport, Crawford County, Wis., near the mouth of the Wisconsin River, appear *Succinea avara*, Say; *Succinea obliqua*, Say; *Limnophysa humilis*, Say; *Patula striatella*, Anthony, and *Vertigo simplex*, Gould. In section 34, Ellenton Township, Grant County, Wisconsin, *Succinea avara*, Say. In the southwest quarter, section 20, Jefferson, Clayton County, Iowa: *Succinea obliqua*, Say; *Succinea avara*, Say; *Patula striogosa*, Gould; *Patula striatella*, Anthony; *Limnophysa humilis*, Say; *Vallonia pulchella*, Mull; *Vertigo simplex*, Gould; *Pupa muscorum*, Linn. In the terrace along the Platte River: *Succinea obliqua*, Say; *Pupa muscorum*, Linn. Twenty feet above Apple River, township 27, range 3 east, Jo Daviess County, Illinois: *Patula striatella*, Anthony; *Pupa muscorum*, Linn.

Of the species occurring in the original loess, six are land species and one aquatic. Of those occurring in the lower terraces, seven are land species and two are aquatic. Five species are common to both horizons. The number of species is too small and the collection too limited to justify drawing conclusions from them.

ORIGIN OF THE LOESS.

The broad question of the origin of loess does not fall to us for discussion here. There may be various deposits that have been styled loess and these may have been formed at different times, possibly by different agencies, and not improbably under different specific conditions. We are only required here to consider the theoretical aspect of the formation that laps upon the driftless region.

Æolian hypothesis.—So far as the attenuated border of the loess that lies out upon the driftless region is concerned, the æolian hypothesis of Baron Richthofen presents many attractions. The eastern bluffs along the Mississippi are frequently crowned by dunes of fine sand blown up from the valley below. These are usually composed of finer sand than is common to dunes in general, and this graduates almost imperceptibly into silt scarcely coarser than that of the loess itself; indeed, not coarser than much loess on the face of the bluffs of the Mississippi, whence, indeed, the dunes seem to be partially derived.

From these dunes there spreads backward to the east—i. e., to the leeward—a mantle of fine sand grading indefinitely away into a deposit indistinguishable from loess proper. In like manner, enlarging the conception, we might conceive the whole of the loess border to be but the attenuated margin of a wind-drift mantle whose source lay in the arid west. But if we enlarge the sphere of observation to correspond with the enlarged conception, the facts of distribution and of structure do not clearly support the hypothesis. It would exceed our limits to enter into the details of this distribution to a sufficient extent to make it clear that the objection is valid. But even confining ourselves to the region under consideration, the distribution, considered in detail, fails to closely accord with the æolian hypothesis. The thickening toward the Mississippi, as well as toward the Iowa drift, is not clearly in accord with it. The coarser character and manifest stratification of the material along the Mississippi at heights of 200 to 300 feet above its present bed and the similar stratification and the gradation into sheets of sand, clay, and drift on the Iowa border[1] and in Minnesota,[2] seem to imply aquatic agencies.

We do not, however, understand, as many writers seem to have done, that the region over which the fine, wind-borne silt was *deposited* was necessarily an arid tract. The aridity postulated by the æolian hypothesis needs only to have affected the territory of derivation. Nor do we understand that fine, wind-borne silt, drifting, *in suspension*, over a grassy plain or a forest would necessarily accumulate in dune-like heapings. The phenomenon of dune accumulation is not identical with that of floating-dust deposition. Floating dust might not gather in very different quantities on the windward and leeward sides of verdure-clothed hills, though we incline to think that there should have been a noticeable difference in this respect. But, granting the utmost reasonable latitude in these respects, we fail to find that accord between hypothesis and observation which is the necessary sanction of an acceptable hypothesis.

A modified phase of the æolian hypothesis has occurred to us that escapes some of the objections that lie against a derivation of the material from the arid tracts of the west. If the terminal zone of the ice sheet in its decadence exposed at its surface much fine material liberated from the ice by superficial melting—as has been thought probable by some glacialists—this, being bare of vegetation, might be superficially dried and drifted away by the winds that swept across or descended from the ice fields. The material so derived would have the mineralogical characters of glacial silt and the distribution would be circumglacial. This hypothesis, however, fails to explain the predominant distribution of loess along the great valleys.

[1] McGee, loc. cit.

[2] Winchell, Geology and Natural History Survey of Minnesota, Sixth Ann., p. 105.

Without elaboration, it may be remarked that the distribution, both topographic and areal; the conspicuous stratification of the thicker portions near the great water-ways or on the thick borders overlooking the loessless drift; the occasional occurrence of aquatic shells; the ingredient of lime and magnesia, the latter of which cannot be referred to the included shells nor to residuary earths, unless in the arid area of derivation these latter were different from those we have examined in the driftless regions within and without the glaciated territory; the association of the loess with the drift in its distribution, and, in some quarters, their intergradation—all these points combined seem to us to support some phase of the aquatic hypotheses which have been almost universally entertained by the students of this phenomenon in the Mississippi Valley.

But in setting aside the æolian hypothesis we exclude the agency which seems best fitted to free us from the topographic difficulties which the singular distribution of the loess presents. There is nothing in the present topography to favor the belief that a body of water had its eastern margin on the rolling land along the east side of the Mississippi and its western border high up on the rough country of Eastern Iowa and Minnesota. We are here brought face to face with two seemingly grave difficulties: (1) that the west side and northern portion of the belt of loess are higher than the eastern and southern; (2) that to the south there is no manifest barrier to restrain the supposed body of water. The loess belt is 40 miles in width, and hence cannot have had any notable declivity in any direction, else the depositing water would have become a torrent in which the deposition of fine silt would have been an impossibility, even if we can conceive an adequate source of supply for such a stream. Even if the gradient were uniform between the loess summits and the Gulf of Mexico, the slope must have been more than twice that of the present Mississippi River, the relative attitude of the region being supposed to be the same then as now. This is a slope quite inconsistent with loess deposition.

Ice dams.—Nowhere on southern slopes can an ice dam be predicated on better circumstantial evidence than here. A great sheet of drift no less than 340 miles wide wraps around the driftless area on the west and joins a still greater sheet that borders it on the east, so that the two coalesce for 200 miles below it. If there are any grounds for doubt that this coalescence of the drift was produced by a junction of glaciers flowing around the driftless area, it would seem that a similar skepticism would lie with even greater force against any other supposed instance of glacial damming on the southern loess-covered slopes. We do not here include, of course, the ponding of waters on northern slopes against the edge of the great northern mer de glace, where the conditions were of a very different order.

But the view that the driftless area was inclosed in ice and that it was flooded by waters so imponded does not seem to us to be supported by the evidence drawn from the character of the assortment of this peculiar material, nor from the form of the deposit, nor from its distribution; in short, the hypothesis of an ice dam fails to satisfy the conditions of the problem, even in this region, where, above all others, the hypothesis would seem to be applicable. In the first place, the recognized loess mantles only the western portion of the driftless area. If glacial waters coming forth from the ice on the west side spread out a covering of silt from 5 to 40 feet deep and 40 miles wide, is it not strange that waters issuing from the eastern border did not in like manner cover that side, the mer de glace in this direction being even more extensive and the present slopes equally or more favorable?

Aside from this difficulty, we find the loess spreading over the drift south of the district and seeming to reach continuously downward even to the Gulf of Mexico. We have reconnoitered the vicinity of the Mississippi for 100 miles south of the driftless region, and have found the loess adjacent to it spreading over the uplands and seeming to be continuous with the well-known belts that accompany the Mississippi and Illinois Rivers and reach southward far beyond the ice limits. On the east side of the Mississippi the loess of the driftless region spreads without any discernible break in its continuity over the drift in Carroll, Whiteside, Henry, Starke, and Peoria Counties, Ill., to the loess adjoining the Illinois River, as well as being continuous with that bordering the Mississippi, save the interruptions of valleys which have manifestly suffered much post-loessial erosion. While we have not traced this mile by mile and while theoretically we entertain a belief in the possible formation of loess at different times—indeed a possible succession of loess deposits corresponding with successive favorable conditions, just as we believe in a succession of drift deposits following each other under somewhat similar environment—we have not yet succeeded in forming even a hypothesis concordant with the facts known that relieves the postulate of an ice dam of these fatal objections.

It seems unnecessary, therefore, to entertain the consideration of the competency of ice, under such conditions, to form an effective dam capable of maintaining a lake with a depth of 700 feet.

If the hypothesis of an ice dam fails here, it much more manifestly does so when applied to the loess as a whole. It has no possible application to the broad belt that stretches from the outermost edge of the drift to the Gulf, and which attains altitudes of 250 feet above the present Mississippi, and spreads widely over the country lying east of the present Mississippi Valley. In Mississippi and Tennessee, as described by Hilgard, Safford, and other geologists of the region, and confirmed by our own recent observations, there spreads eastward from the typical loess tract a mantle of loess-like loam similar to the modified loess-border of the driftless region, stretching out to a like almost undefinable extent, undulating with the pre-existent surface. While there is room here also for possible, or even probable, discriminations not yet worked out, it is clear that these do not affect the general problem, namely, what were the conditions that made such a deposit possible? This problem remains essentially the same whether we suppose this southern deposit to be strictly contemporaneous in time and continuous in distribution with the analogous formations of the Upper Mississippi or not. If caused by an ice dam, the loess should suddenly terminate at the locality of the barrier, and the stream below would have been in nowise affected by it. But in this instance conditions must have existed below any possible ice dam, which permitted the deposit of a mantle of loess 250 feet above the present level of the Mississippi.

The comparative antiquity of the loess of the Lower Mississippi, as indicated by the erosion it has suffered, approximates, in our judgment, to that of the more northerly regions, and, so far as this difficult and somewhat uncertain line of evidence is concerned, we find no reason for departing from the general conviction of the geologists of the region that the great loess streams are essentially continuous and contemporaneous from the Gulf region to the Upper Mississippi and Middle Missouri.

The distribution of loess along the rivers of Illinois, and extensively along the Missouri from Dakota southward, presents a series of problems in which similar difficulties are to be met, many of them involving the singular feature of different altitudes on the opposite borders of the loess belts. The theory of ice dams, therefore, seems to us entirely inapplicable to a large part of the broader problems and specifically inadequate in the special question in hand, where the conditions might be presumed to be especially propitious.

Notwithstanding our disbelief in a permanent ice dam, it seems to us entirely probable that at the time of maximum glaciation—not the time of maximum loess deposition—the drainage outlet of the driftless area may have been occasionally, perhaps frequently, blocked by engorged ice and the region more or less extensively submerged. To such action may perhaps be attributed some of the rare instances of transported blocks that can equally well be attributed to human agency. Such an instance is that of the sandstone blocks described by Professor Whitney (Geology of Wisconsin, Vol. I, 1862, pp. 137–139), which he thinks must have been lifted 125 feet from their original place. A temporary damming at spring time with a rapid rise of the ponded waters would furnish the conditions for such lifting and local transportation.

To such occasional ponding of waters may perhaps be due the microscopic minerals mingled with the residuary earths, since, if of aqueous origin at all, the submersion cannot well be supposed to have been protracted, because of the extreme meagerness of the deposit.

Ice attraction and crust deformation.—Two hypotheses remain to be considered. Both postulate that the loess is glacial silt, deposited by waters issuing from the margin of the glacier and bordering it as fringing lakes or broad, lake-like rivers.

The difficulties in the vertical distribution are met, under one of these hypotheses, by the claim that the attraction of the ice was sufficient to change the surface of the water so as to give the loess the distribution which it is observed to possess. As this question of the possibilities of ice attraction enters into a large number of problems connected with glacial phenomena, we have submitted representative problems to Mr. R. S. Woodward, of the United States Geological Survey, who has kindly undertaken their mathematical solution.[1]

Possibilities of ice attraction.—Three considerations enter into the problem:

1. The ice mass may be thought to have drawn up the ocean about it, so as to give the Mississippi River and its tributaries an estuarine character, inviting the deposit of silt.

2. On the other hand, the abstraction of water from the ocean to form the ice may be thought to have lowered its level and to have counteracted the effects of attraction.

3. The tilting of the water-level, due to ice attraction, may be thought to have so changed the drainage as to furnish the requisite conditions for loess deposition. This would affect the surface slopes of lakes and rivers independently of their connection with the ocean.

It is necessary, therefore, to determine (1) the possible abstraction of oceanic water, (2) the change of slope adjacent to the ice, and (3) the possible elevation of the ocean level.

The amount and precise form of the ice mass are yet unknown, but assumptions may be made that cover the range of all probable cases.

In the computations whose results are here given it has been assumed that the ice was distributed symmetrically about an axis or "center of dispersion." While certainly not strictly true, this is sufficiently approximate for the quantitative limital applications here sought. Several assumptions as to the rate of increase of thickness from edge to center have been made, varying from the purely ideal case, in which the full thickness is attained at once, to the improbable opposite extreme, in which the increase is exceedingly slow. The real cases lie between these extremes.

[1]A more complete exposition of Mr. Woodward's investigations will be published as a bulletin of the Survey.

In the accompanying figure the lines 1, 2, 3, 4, and 5 indicate a portion of the profiles assumed, drawn to scale, but vertically exaggerated. The real profile of the ice probably lay between curves 3 and 4.

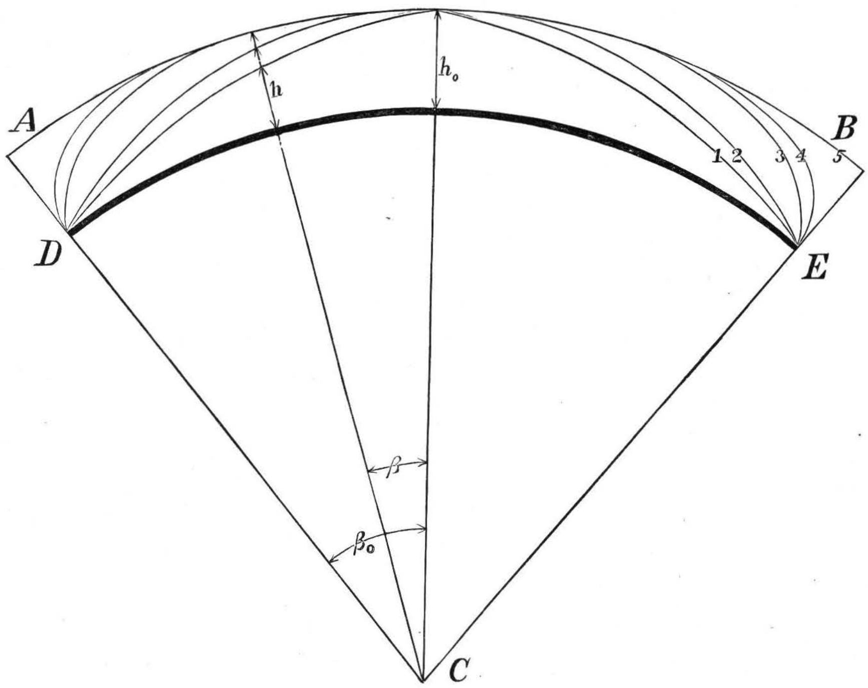


FIG. 48.—Diagram illustrating the several profiles of the ice cap assumed in the accompanying computations.

C center of earth, D E surface of earth. Curves 1, 2, 3, 4, and 5 represent profiles of ice when $n=1$, $n=2$, $n=6$, $n=10$, and $n=\infty$, respectively, as defined by the accompanying formula (1). Scale for D E C, $\frac{1}{84000000}$; for the ice cap, $\frac{350}{84000000}$.

An empirical formula which defines the extent and slope of a great variety of cases is

$$h = h_0\left(1 - \left(\frac{\sin\frac{\beta}{2}}{\sin\frac{\beta_0}{2}}\right)^n\right) \qquad (1)$$

in which h is the thickness of the mass measured in the direction of the earth's radius at the angular distance β from the axis of the mass; h_0 is the thickness of the mass along its axis; β_0 is the angular radius of the mass, or the limiting value of β; and n is any positive integer. This formula includes the case of a mass of uniform thickness, the index n being in that case infinite.

In the computation the following values have been assumed for the axial thickness and angular radius of the mass, viz:

$$h_0 = 10{,}000 \text{ feet.}$$

$$\beta_0 = 38^\circ$$

This value of β_0 corresponds to about 2,600 miles measured along the earth's surface, or about the distance from the glacial margin in the interior basin to Greenland. As the ice quite certainly had a less extension in most other directions, the areal extent here assumed is generously large. It is also very nearly that radial extent of a mass of uniform thickness which would produce the maximum upheaval of water along its border.

The maximum thickness, 10,000 feet, is less than that computed by some glacialists, but we have not ourselves found good reasons for thinking it was greater than this. While Geikie, Cook, Smock, and others have shown that the slope of the upper surface of the ice near the border was 25 to 35 feet per mile, it seems to us inherently improbable that this gradient would hold after a considerable depth had been reached, but would be replaced by a progressively lower slope till it reached a plane at the center. The large estimates are obtained by projecting border slopes backward—to us, a manifest error.

As the effects of masses corresponding to several values of the index n have been computed, it will be of interest to define with some precision the shape of the exterior surface of each mass. To do this it will suffice to give the slope in a meridian plane of the surface of any mass at several points between the axis and the border. These slopes are given in the following table for each of the masses defined by the index $n = 1$ to $n = 10$; they express the inclination of the bounding surface of the mass to the spherical surface of the earth.

Table showing meridian slopes of bounding surface of the attracting ice mass.[1]

n	Slopes in feet per mile corresponding to $\beta=$								
	0°	5°	10°	15°	20°	25°	30°	35°	38°
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
1	3.88	3.88	3.86	3.85	3.82	3.78	3.75	3.70	3.67
2	0.00	1.04	2.07	3.08	4.07	5.04	5.96	6.84	7.34
3	0.00	0.21	0.83	1.85	3.26	5.02	7.10	9.47	11.00
4	0.00	0.03	0.29	0.99	2.32	4.45	7.53	11.66	14.67
5	0.00	0.01	0.10	0.49	1.55	3.70	7.48	13.46	18.34
6	0.00	0.00	0.03	0.24	0.99	2.95	7.14	14.92	22.01
7	0.00	0.00	0.01	0.11	0.62	2.29	6.62	16.08	25.68
8	0.00	0.00	0.00	0.05	0.47	1.73	6.02	16.97	29.34
9	0.00	0.00	0.00	0.02	0.23	1.30	5.38	17.64	33.01
10	0.00	0.00	0.00	0.01	0.13	0.96	4.75	18.10	36.68
∞	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	∞

[1] The tabular values are given to the nearest hundredth of a foot. All slopes designated 0.00 feet, except those in the last line and second column of the table, are therefore less than 0.01 foot per mile, but greater than zero.

The numbers in the above table show that for values of n greater than unity, the bounding surfaces, as defined by equation (1), slope up with decreasing rapidity from the border to the axis in each case. For large values of n, the steep slope near the border diminishes rapidly, so that the bounding surface reaches its maximum height, nearly, within a short distance of the border. In the case $n=1$, however, the slope of the bounding surface is steepest at the axis of the mass and decreases slowly from the axis towards the border. The features here enumerated will hold for any extent of mass, i. e., any value of β_0. It will be seen also by reference to equation (1) that the slope for any value of n is directly proportional to h_0, the axial thickness of the mass. Hence the slopes corresponding to any other thickness than that assumed (10,000 feet) may be readily computed from the table.

It would be possible to assign the effects of an indefinite variety of other forms, but, in the absence of more complete actual data respecting the ancient ice, the simple forms whose slopes have been computed are considered adequate.

1. To form an idea of the volume of water consumed in the formation of the above assumed ice masses, the thicknesses of spherical shells, supposed to envelop the earth and to have volumes equal to the ice masses, respectively, have been computed. Since the sea covers nearly three-fourths of the earth's surface, the products of these thicknesses by four-thirds will represent approximately the necessary lowering of the sea level, if the water in the ice was drawn from the sea. The value of T, the thickness of the equivalent spherical shells, and $\frac{4}{3}$ T are given in the table below for the same values of the index n as those used in the preceding table:

Table showing thicknesses, T, of spherical shells of equivalent value with ice masses, and equivalent lowering of sea level $\frac{4}{3}$ T.

n	T	$\frac{4}{3}$ T
	Feet.	*Feet.*
1	353	471
2	530	707
3	636	848
4	707	943
5	757	1,009
6	795	1,060
7	824	1,099
8	848	1,131
9	867	1,156
10	883	1,177
∞	1,060	1,413

As the value of n which probably corresponds nearest to the truth lies between 6 and 10, the lowering of the ocean would be from 1,000 to 1,200 feet, if the area of the ice was as great as assumed and the water was derived from the ocean and not from the melting of a cap at the opposite pole. If the latter were the fact there might be no draft on the ocean. But the present extent of land in the southern polar regions is so limited as to raise a doubt of its competency to furnish an adequate supply, even under the hypothesis of alternate glaciation.

2. To determine the position of the disturbed, relative to the undisturbed, surface, it was thought sufficient to compute the elevations of the water (1) at the center of the attracting mass, (2) along its border, and (3) 180° from the center. As the slope of the disturbed surface along the border of the mass is of considerable importance, its average value for a distance of 1°, or 69 miles, from the border has been determined. These elevations and slopes are given in the following table for each value of the index n used above to define the shape and volume of the ice. The plus sign indicates elevation and the minus sign depression of the disturbed, relative to the undisturbed, surface. It will be remembered that $n = \infty$ corresponds to a mass of uniform thickness.

Table showing the position of the disturbed, relative to the undisturbed, sea surface, and the slope of the disturbed surface near the border.

n	Position of disturbed, relative to undisturbed, sea surface.			Average slope per mile of disturbed surface within 1° of the border of ice mass.
	At center of ice mass.	Along border of ice mass.	180° from center of ice mass.	
	Feet.	*Feet.*	*Feet.*	*Feet.*
1	+ 695	+ 139	− 95	0.15
2	+ 895	+ 215	− 142	.24
3	+ 985	+ 265	− 170	.30
4	+ 1,035	+ 300	− 189	.34
5	+ 1,067	+ 326	− 202	.37
6	+ 1,088	+ 347	− 212	.40
7	+ 1,104	+ 363	− 220	.42
8	+ 1,116	+ 377	− 226	.43
9	+ 1,125	+ 389	− 231	.45
10	+ 1,133	+ 398	− 235	.46
∞	+ 1,198	+ 573	− 281	1.00

As already explained, the numbers in the second, third, and fourth columns of the last table assign the position of the disturbed or new equipotential surface relative to the undisturbed surface. The effect of the rearranged free water, which might possibly increase the computed results by slight amounts, has been neglected. The results in the second column are heights to which the water would rise at the center of the mass if brought within it in any manner, as by a canal, and left free to assume equilibrium. If the amount of free water were sufficient, it would rise or fall, to the extent indicated in the third and fourth columns, respectively, at points along the border, and at the antipodes of the center of the mass.

The slopes given in the fifth column will apply to isolated bodies of free water adjacent to the ice mass, and also to the sea surface in the same vicinity, whether there be sufficient water to rise to the heights indicated in the second column or not. The maximum possible slope of the disturbed surface would occur at the immediate border of a mass of uniform thickness. This slope is found to be 1.80 feet per mile and corresponds to a plumb-line deflection of 72″. Since it is incredible that the ice mass presented at its border anything like a vertical wall 10,000 feet high, we infer that a mass whose maximum, or axial, thickness was 10,000 feet would be quite inadequate to produce a slope of 1.80 feet per mile.

Again, since all the results in the last table are directly proportional to the axial thickness of the ice, to produce as great an average slope as two feet per mile, within one degree of the border of a mass having the more probable shape defined by the index $n = 6$ to $n = 10$, would require an axial thickness, in round numbers, of 50,000 feet or 9½ miles. To give, with a like surface contour, a slope of five feet per mile—an inclination reached by the ancient beach of Lake Ontario (Gilbert)—would require an axial thickness of 125,000 feet.

To produce average slopes as great as four or five feet per mile for any distance from its immediate border, the ice mass would require an enormous thickness, which implies for any large areal extent a heavy draft on the visible supply of water. The minimum thicknesses of ice masses, of varying radial extent, which would produce an average slope of five feet per mile within 1° of their borders, are shown in the following table.[1] These values are computed on the improbable supposition that the masses are of uniform thickness. The volume of each mass is indicated by the equivalent lowering of the sea level, or $\frac{4}{5}$ T, as explained above.

Table showing the minimum thicknesses of ice masses of varying radial extent competent to produce an average change of water level of five feet per mile within 1° of their borders, and the equivalent lowering of the sea level.

Angular radial extent of mass.	Minimum thickness of ice.	Equivalent lowering of sea level.
Degrees.	*Feet.*	*Feet.*
10	69,400	703
20	57,500	2,308
30	52,600	4,699
38	50,000	7,065

For masses having moderate surface slopes near their perimeters the axial thickness must be about twice as great as the minimum values

[1] For a given radial extent of mass the slopes are directly proportional to the thickness; so that for slopes of 1, 2, &c., feet per mile the thickness required will be $\frac{1}{5}$, $\frac{2}{5}$, &c., of the tabular values.

given in the table to produce the same average slope of five feet per mile within 1° of the borders. Thus, for the assumed extent of mass (38° radius) and for $n=6$, say, an average slope of five feet per mile within 1° of the border would require an axial thickness of about 125,000 feet, or 24 miles. This corresponds to a lowering of the sea level of 2.4 miles, and, if the quantity of free water were sufficient, to an elevation of the sea along the border of the ice of about 4,000 feet. The slope of the exterior surface of this assumed ice mass would be very steep near its border, viz (see table of slopes), 275 feet per mile, which is widely at variance with inductions from observations.

Confining further investigation to the working axial thickness of 10,000 feet, we may inquire as to the extent of the variation of sea level at any point of the earth's surface, on the supposition of an alternation of glaciation at the poles. For this purpose it is simply necessary to compute the elevation of the disturbed surface at the angular distance a of the point in question from the pole or axis of the ice mass and for the point $180° - a$, and take the difference between the results.

Table showing the possible variation of sea level at different points on the earth's surface caused by alternate glaciation at the poles, the maximum mass being of 10,000 feet uniform thickness and of 38° radial extent.

Angular distance from pole of ice.	Elevation of disturbed above undisturbed surface.	Variations in sea level from epoch of minimum to epoch of maximum glaciation.
°	*Feet.*	*Feet.*
0	+1,198	1,479
10	+1,169	1,449
20	+1,076	1,352
30	+ 893	1,163
40	+ 441	702
50	+ 185	434
60	+ 46	279
70	− 43	170
80	− 106	80
90	− 152	00
100	− 186	80
110	− 213	170
120	− 233	279
130	− 249	434
140	− 261	702
150	− 270	1,163
160	− 276	1,352
170	− 280	1,449
180	− 281	1,479

The elevation of the disturbed surface at the border of the ice is 573 feet (see table on page 295), and the possible variation of sea level at that point is 836 feet.

Since the maximum effects are of most interest, the variations in sea level on the supposition that the ice cap was of uniform thickness have been derived. The results, as may be inferred from the table on page

296, will not differ materially, except for points near the border of the ice, from the results which would be derived on the supposition of a sloping ice mass corresponding to the index $n=6$ to $n=10$. The results are given in tabular form above for intervals of 10° from either pole.

The variation of the slope of the sea surface at any point during the interval between the extremes of glaciation at either pole will equal the sum of the slopes at that point for the two epochs. The maximum variation is, however, only slightly greater—about 1 per cent.—than the maximum slope already computed, and requires, therefore, no further consideration.

We may now apply these results to the problem of the loess, or, rather, to that limited phase of the great puzzle that calls for our present consideration.

The loess, on the borders of the driftless region, reaches an elevation of 1,285 feet above the ocean level. (Considerably greater heights are attained in the Missouri Valley.) By referring to the table it will be seen that this is greater than the maximum effects which an improbably large mass of ice (10,000 feet *uniform* thickness and 38° angular radius) would effect at its center. But the loess could at best only have been formed at the edge of the ice, or 38° from the center, where the elevation of the sea level would be but 573 feet.

Besides, no allowance is here made for a lowering of the sea level from abstraction of water, which probably amounted to something, even if the glaciation alternated from pole to pole, and might, under other suppositions, have completely balanced and even overbalanced the effects of attraction. If it is thought that we should assume a greater maximum thickness of ice, it must, in offset, be conceded that deduction must be made for the undoubted thinning of the ice at the margin, and also a large reduction in the areal extension. It does not appear, therefore, that the attraction of the glacial mass could have lifted the ocean and ponded back the Mississippi waters so as of itself to cause the deposition and existing distribution of the loess. Had there been a solid ice cap 10,000 feet thick throughout, reaching from a center in Greenland to the border of the driftless region, it would have lifted the sea level much less than half way up to the loess-capped hills of Iowa.

If we were entitled to call in the remarkable elevations reached by the Chinese loess, the inadequacy of the hypothesis would be conspicuous, but the Chinese problem may have elements radically different from those under consideration; at least it is unsafe to appeal to it here.

It seems, therefore, perfectly safe to assume that whatever influence the attraction of the ice exerted upon loess deposition in the driftless area came through a change in the surface slope, so to speak, of the inland waters.

On the assumption of an ice cap 5,200 miles in diameter, with Greenland as its center and with a surface contour represented by $n = 10$ of the formula—which is all that observation will allow—and a thickness at the center of 10,000 feet, the change of water level within 1° of the border would average .46 foot per mile. If the central thickness were 20,000 feet, the change would be .92 foot per mile. To give the same mass with the real distribution of the ice would probably require more than twice that thickness, so that a change of slope one foot per mile would seem to be an overgenerous allowance for possible attraction. Indeed, in our judgment one-half foot is ample.

But the slope from the summit altitudes of the loess on the northwestern side of the driftless area to its southeastern limit, as well as it can be determined under the difficulties of its attenuation, is from two to three feet per mile.

To eliminate any doubt that may arise from the vague southeastern delimitation of the loess, let the ocean be supposed to have been lifted to the maximium amount computed for the assumed larger mass of ice, and then the slope from the summit of the loess in Iowa to this lifted ocean border be computed. A decline of more than two feet per mile for a distance of 400 miles will be the result.

With other facts of like import falling into consilience with these, the conclusion that ice attraction is quantitatively insufficient seems compelled.

But, as geologists, it is our function to bring this hypothesis to the crucial test of geological facts rather than mathematical computations. If the present topographic attitudes then existed, we encounter serious difficulties in its application, growing out of the distribution of the loess with respect to the ice masses.

If the ice stream, 340 miles wide, that passed by on the west side of the driftless district was able to draw up the waters on its flank so as to cover the adjacent region with a belt of loess 40 miles wide and reaching heights 700 feet and more above the present Mississippi, why did not the ice on the east side, which extended back many hundred miles, cover that side to at least as great heights? Indeed, why did not the combined attraction of the ice on all sides cover the whole region with water without regard to an ice dam at the south? If the ice on the other sides had a competency equal to that supposed to be indicated by the loess on the west, this must have been accomplished; but we find the border of the drift on the east side of the driftless region unattended by evidence of a general persistent submergence, in the form either of loess or of any other subaqueous deposition. So, likewise, we find the border of the ice field of the later epoch on the east and north of the driftless region unattended by evidences of water drawn up about the margin by ice attraction, and, in this instance, we have specific evidence that such bodies of water did not exist, for along the outer side of the moraine there are overwash plains and valley streams of coarse drift that could have been deposited where they are only by strong currents flowing away from the border at considerable gradients. These streams, as we have heretofore stated, flowed down through the deep valleys of the driftless region 600 feet lower than the summit of the adjacent loess. In the one glacial epoch, therefore, there were conditions which permitted the deposition of the loess over the heights broadly, while in the other strong currents swept down through deep valleys. Now, if there be any advantage in respect to the attractive powers of the ice in the two epochs, it probably lay in favor of the later; for the energetic action of the later sheet and the massive moraines which it pushed up at its edge appear to indicate that its border was thicker and its adjacent body more massive than that of the earlier glacier, which spread itself out so innocently over the plains of Iowa that it did not destroy the general prevalence of the vegetal interglacial deposits that lie between the upper and lower tills, assuming, of course, that the overlying till was spread out by a glacier, which is necessarily involved in the hypothesis we are discussing.

There is a further difficulty involved in this hypothesis. If the attraction of the ice was competent to draw up about the glacier's margin such bodies of water as those indicated by loess distribution, these waters should have followed, as it retreated, over similar slopes, subject to some allowance for the thinning of the ice under the action of wasting influences. Deposits which may be interpreted as indicating the presence of peripheral waters are somewhat prevalent over the area abandoned by ice, but these are not usually of a class closely approximating the loess.

Crust changes.— The second hypothesis assumes that the attitudes of the surface in the several glacial stages were not identical, either with each other or with the present one. This hypothesis is not in itself antagonistic to a belief in ice dams where there is specific evidence of their existence, nor is it at all incompatible with a belief in any measure of attractive influence on the part of the ice. Indeed, depression of the crust would be aided by the weight of any waters that might be drawn up about it by the ice. Whatever attractive force the ice may have had must be an element in any complete hypothesis based upon a belief in changes of crust attitude.

The general hypothesis of crust changes has subordinate phases which need to be stated. Changes in the attitude of the crust may be supposed to have taken place as purely inter-current phenomena, having no direct relationship to the presence of the ice or to the progress of glacial events. Such oscillations have marked all stages of geological history, and are due to occult causes into which glacial students have no occasion to inquire, though they must take account of the fact. Such changes have probably been ever in progress, in some quarter of the globe, if not in all quarters, throughout the lapse of geologic time, and that some of them should have occurred during the glacial epoch, and have made themselves felt upon glacial phenomena, is a belief entirely in accord with geologic history. Such changes would probably be fortuitous, so far as the glacial field is concerned. There would be no conformity, except by accident, to the territory occupied by the ice.

If general considerations could have much weight in anticipating where such movements would occur and of what order they would be, it would not be unnatural to suppose that those areas which in the last preceding geological ages occupied attitudes and elevations different from the present would be those most likely to partake of such movements. For instance, in the Cretaceous period, the sea occupied the great plains to the west and came up to the very border of the driftless region, if, indeed, it did not actually encroach upon it. So, also, in the Tertiary age, the area lying to the westward of the driftless district was a low basin as late as the Pliocene period. There are several considerations, some of which will appear in the following discussion, which render plausible the view that the lingering effects of the Pliocene depression were felt in the earlier Post-Pliocene epoch. So, in like manner, there are several classes of phenomena in the Appalachian region that have suggested to several geologists independently the view that that tract has partaken of relatively recent elevation.

On the other hand, the deep old cañons of many of the tributaries of the Mississippi, and of that stream itself—as indicated by the observations of Hilgard on the deep-laid Orange sand in its lower portion, the artesian wells to which we have before alluded in its upper course, and the deep erosions of the Cretaceous and Tertiary strata in the Upper Missouri region—suggest, with equal or greater force, the probability of a Post-Tertiary elevation. These suggestions are not necessarily incompatible. They may be reconciled by supposing a warping in the general crust movement which the continent experienced in the later geological epochs. It may be supposed that at the time of the earlier glacial epoch the Tertiary basin of the Middle Missouri region had not fully attained its present elevation, while in the Lower Mississippi region the Tertiary estuary had not received its present relative elevation on the eastern border. The latter is rendered plausible by the fact that the present Mississippi flood-plain lies on the western side of the old estuarian depression, as well shown by the general geologic map accompanying the report of Mr. McGee in the Fifth Annual Report of the United States Geological Survey.

Our data are much too meager as yet to justify us in fastening upon such hypotheses as these, however plausible they may be and however accordant with our present knowledge, but they are fruitful in suggesting observations and they encourage the hope that all the puzzling features of our Quaternary deposits will find fit elucidation in the mutual light these will shed on each other when all the complex phenomena of the great basin have been gathered and organized into a consistent whole; when bone shall have come to his fellow-bone, in the valley of dead and scattered facts, and a vital interpretation shall have given life to the whole.

Deformations produced by ice.— A second class of deformations have been held by many geologists, ourselves among the number, to be probably due to the presence of the ice itself. These deformations are presumed to arise from three classes of influence:

(1) The weight of the ice, it is held, must necessarily produce compression of the rocks, and whenever the depth of ice loads the surface with a weight that bears any appreciable ratio to the elastic resistance of the rock, a measurable depression of the surface must result. Such a deformity must, in its nature, be confined essentially to the rock immediately beneath the ice, and cannot be assumed to be effective in the territory beyond. But the loess stretches out over the pebble drift and driftless region 40 miles beyond the supposed limit of the ice and considerably more than that beyond any great thickness of it, so that whatever may be the quantitative effects of deformation due to compression beneath the ice, we seem to be unable to derive much help from it in the solution of the puzzle.

(2) One of us has elsewhere suggested[1] that a slight deformation would arise from the reduction of the temperature of the superficial portion of the crust, due to its long-continued occupancy by the ice and the penetration of the strata to the depths of their permeability by cold waters in lieu of those which before had the average temperature of the mild climate of pre-glacial times. The radial contraction due to this would be quantitatively insignificant; but the lateral shrinkage for the broad tracts occupied by the ice would be cumulatively considerable, and if the strain upon the crust were such that equilibrium depended, in any notable measure, upon the tangential support of the superficial portion so affected, the lateral contraction might lead to appreciable depression. For instance, for the tract covered by the drift west of the driftless area the horizontal shrinkage for a lowering of the temperature 15° F.— accepting current estimates of the coefficients of expansion for average rocks — would be about 175 feet. The extent to which this would lower the surface might vary very widely, according to its relations to the other forces that control the status of the crust, which are largely unknown factors. By hypothesis the effects might be very trivial or very important. But probably this agency may be regarded as unimportant, except in special instances of balanced strains.

(3) A third influence due directly to the presence of the ice consists of a supposed bodily depression of the crust under the extra load thus imposed upon it. The validity of this belief depends upon the correctness of the doctrine that the crust is balanced or nearly balanced under the combination of forces, active or potential, affecting it. The question is not simply one of the strength of the crust of the earth, in itself con-

[1] Geology of Wisconsin, Vol. I, 1882, p. 290.

sidered, but one of the surplus power of resistance which it has over and above that used up in meeting the strain and load beneath which it is already laboring and which surplus it can oppose to a new burden. It is manifest, upon consideration, that at every turning point in the oscillation of the crust, where it ceases to descend and begins to ascend, or where it ceases to ascend and begins to descend, there is an absolutely accurate balance between the active forces that are brought to bear upon it. There is also reason to believe that at the intermediate stages between the changes from one movement to another there is an approximation to equilibrium between the several forces arrayed on the side of elevation and on the side of depression. Now, at the stages of absolute equilibrium, theoretically at least, a trivial addition to either side of the balance must initiate a movement. So, also, in the stages of approximate equilibrium, a comparatively slight increment of force on the one side or the other may stay a movement and reverse its phase. The question, therefore, is not whether the superposition of a glacier is competent to overcome the total strength of the crust of the earth, but merely whether it is able to turn the balance of forces from the one side to the other and determine a new movement or a new attitude of equilibrium.

At first thought the validity of this doctrine might seem to be largely dependent upon the condition of the interior of the earth. In some measure perhaps it is. But it appears to us that the foregoing considerations hold measurably true, whatever hypothesis of interior constitution is entertained, consistent with the known facts of crust oscillation, displacement, and deformation.

Now if the depression of the crust under its burden of ice, acting in these three ways, was appreciable, the effects were felt immediately beneath and about the ice. If such a local depression was combined with the supposed lingering of Pliocene depression of the western region, the two would seem to furnish the peculiar attitudes of the surface which the loess distribution seems to demand. The failure of the loess to appear on the eastern border may be plausibly attributed to the fact that, while depression took place in that region, it did not reach a stage of submergence. That depression took place in Eastern Wisconsin at some time during the glacial epoch, there is evidence in the deep river channels and the depressed lake basins. The latter, however, are subjects of controversy, and although our views are composite, embracing a large element of all current ones combined, we will not here urge the point.

But the Rock River, a tributary of the Mississippi, has a channel which, at Janesville, Wis., is 250 feet below the present stream and at Lake Koshkonong 320 feet below it, while the several artesian wells at La Crosse, Prairie du Chien, and Dubuque do not show a depth of the old cañon of the Mississippi much exceeding 100 feet. The bottom of the well at Lake Koshkonong, in the Rock River Valley, though still in drift, is about 120 feet below the surface of the Mississippi at the junction of the two rivers, so that, if the old cañon of the Mississippi at the junction is as much below the present surface as it is in the driftless region (it being understood that the old cañon does not underlie the present course of the river, which there has a rock bottom), there would be no fall from Lake Koshkonong to that point. Or, again, the bed of the old Rock River at Lake Koshkonong is 50 feet below the old bed of the Mississippi, directly opposite on the west. The general law being that tributaries have higher gradients than their primaries, especially when the tributaries are relatively small, it appears improbable that the two cañons could have been excavated to their relative depths in the present attitude of the surface. It is therefore probable that at the time these deep valleys were cut the Rock River bed was relatively higher.

There is perhaps concurrent testimony in the observation that the tributaries of the Mississippi on the east side usually have flat bottoms and a low gradient reaching well back toward their headwaters, as previously described in the discussion of the topographic features of the region. On the other hand, the tributaries coming down from the west usually have steeper inclines with rapids and cascades toward their headwaters, many of which do not seem attributable to diversion of the channel by drift.

These several lines of evidence support the belief that the eastern as well as the western side of the driftless area suffered depression, but that, on the east, owing to greater antecedent elevation, the surface was not brought down to the point of submergence.

We have heretofore called attention to concurrent evidence, springing from other lines of observation, but we may not here turn aside to consider them.

Fully appreciating the fact that much more ample data are necessary to constitute a sure groundwork for belief, and, certainly, fully aware of the imperfection of these brief abstracts from the evidence at command, there yet seems to us a sufficient basis in observation to support the hypothesis that crust depression, whether due to the causes above indicated or to others, played an important part in the conditions which fostered the deposition of the loess and gave it its remarkable distribution.

Source of the silt.—The constitution of the loess seems to us to indicate that it is an assorted variety of glacial silt directly derived from glacial waters. The clearest testimony to this seems to us to lie in the calcareous and magnesian ingredients which it so generally presents. It might be maintained that the calcareous element is due to molluscan shells and their débris imbedded in it, but the calcareous ingredient has a much wider and much more uniform distribution than the shells, and the well preserved delicate fossils are not accompanied by a sufficiently abundant series of fragments of various degrees of comminution to make it probable that the widely disseminated calcareous element is due to the comminution of fossils or to the solution and redeposit of their material. But the stronger argument lies with the magnesia, which is not a notable constituent of the molluscan shells, and there seems no evident source for it except the drift in which it abounds. The superficial residuary clays are nearly free from both, so that wind action cannot plausibly be supposed to have derived the loess from them. A similar argument may be drawn from the undecomposed microscopic particles of the silicates above discussed.

These arguments are not quite conclusive against the wind theory, because in arid and nearly soilless regions the mechanical action of winds and of occasional torrential rains plays a large part in the formation of detritus, while decomposition is less active. Precisely what is the character of the finer constituents of the soils of the western arid regions is yet undetermined, but it is not irrational to suppose that they embrace a larger element of undecomposed material than those of the humid regions.[1] On the other hand, the wind-drifted sand of arid tracts is known to be more worn by attrition than water-rolled sand, and particles of loessial size would probably also be worn by violent impact against obstructions when driven by the desert gales. No trace of such action has been detected in the microscopic examinations.

Taken in connection with the distribution, the above considerations appear to point to glacial silt as the parent formation of the loess under consideration — without prejudice to the view that there may be closely similar deposits of different origin.

Time of the deposit.—The loess deposit on the border of the driftless district appears to have been contemporaneous with the closing stages of the second episode of the first glacial epoch. The observations of Mr. McGee, on its western border, seem to necessitate the contemporaneous presence of the ice over the loessless drift plains of North Central Iowa. The coexistence of the ice over these plains, with a body of water in which a deposit so completely assorted as loess was taking place, without more than very rare instances of erratics dropped from floating ice, is a puzzle — indeed, a seeming incompatibility — for which we find no entirely satisfactory explanation. The nearest approach to it we find in supposing, first, that the bordering waters which deposited the loess were shallow, and hence had little competency to detach and float away ice masses. This incompetency would be increased by the hills and highlands which, to a considerable extent, formed the limit of the loess in the region where the phenomena prevail. In the second place, it is possible that the border of the ice, in the thinned state at which it is supposed to have arrived at the time of the deposition, was largely implanted with glacial débris and covered superficially by wind drift accumulations and the residue of ablation, so that its melting was delayed,

[1] Cf. Report on a Series of Specimens of the Deposits of the Nile Delta, obtained by the recent Boring Operations. By J. W. Judd. Proc. of the Royal Society, No. 240, 1886.

and it formed a barrier of commingled drift and ice, which prevented general berg action along the border so protected. These conditions would only obtain in topographic situations peculiarly adapted to their development. But it seems not impossible that such conditions obtained along the highlands of Western Iowa and Minnesota. Perhaps some plausibility is gained for this hypothesis by the observation that in Central and Southern Iowa, where the conditions above indicated could not so plausibly be supposed to have obtained, the bowlder drift, as described by Mr. McGee, graduates up into pebbly clay, and then into pebbleless clay, and thence into loess, the whole seeming to be a consecutive series. This continuity seems to imply that there was a gradual passage from conditions favorable to the deposit of subaqueous stony clays into conditions that excluded the stony element and led to the measurable separation of the clayey constituent. These may have been found in the thinning and retreat of the ice and the shallowing of the waters. The shallowing of the waters might develop increased but very gentle currents, which would remove the most easily transportable constituents and leave the less fine silt.

The assortment of the material.—Our observations upon the clayey matrix of the tills, upon the clays that collected in many of the lake basins that abound on its surface, and upon the sediment of turbid glacial waters indicate that "glacial milk" deposit and loess are not precisely identical. There appears to have been a remarkable classification of material. The coarser must have been persistently and steadily kept behind, while the finest, at least in the proportion necessary to give plasticity and imperviousness, was excluded. The requisite conditions may perhaps have been found in the fact that the loess-depositing waters were neither true lakes nor true rivers, but assumed an intermediate fluvio-lacustrine character, possessing sufficient onward flow to prevent the deposition of a large proportion of the clayey constituents of the silt they bore, while the coarser particles were dropped; the motion, on the other hand, not being sufficiently violent to transport sand, except in the immediate vicinity of the source and in the immediate valleys of the greater streams, where the currents were somewhat appreciably accelerated.

It is difficult to draw a satisfactory distinction between a lake and a river, but, considered as geologic agencies, the distinction should probably be drawn with reference to the competency of the water to move material along its bottom. A river not only transports matter in suspension, but rolls it along its bed. A lake, aside from winds, is devoid of the latter power. Its feeble currents may transport matter in suspension, as they certainly do in solution, but in a true lake matter is not rolled along the bottom by the current passing through it.

The loess probably represents the debatable ground between the two. The coarser stratified portion along the immediate valleys of the great streams seems clearly on the fluvial side of the line, while the broad, loam-like mantle apparently lies on the other side.

The assortment was not, probably, entirely due to the conditions of deposition, but, probably, quite largely to the character of the material supplied to the waters. Had they been greatly deficient in the larger grade of particles that characterize loess, it is doubtful whether the aqueous agencies of assortment would have effected a sufficient degree of classification to have produced a porous product. The rock flour produced by glacial grinding was doubtless rich in particles of the appropriate grade. Samples of glacial sediment from Mount Shasta, furnished by Mr. Diller, show a larger percentage of particles of the coarser loess grades than the loess itself. Probably the waters of the Quaternary glaciers contained a larger clayey element derived from old residuary earths and from clayey strata, and it is probable that only a moderate amount of elimination of clayey constituents was necessary to bring the residue within the limits of the loess grades.

CHAPTER V.

TERRACES.

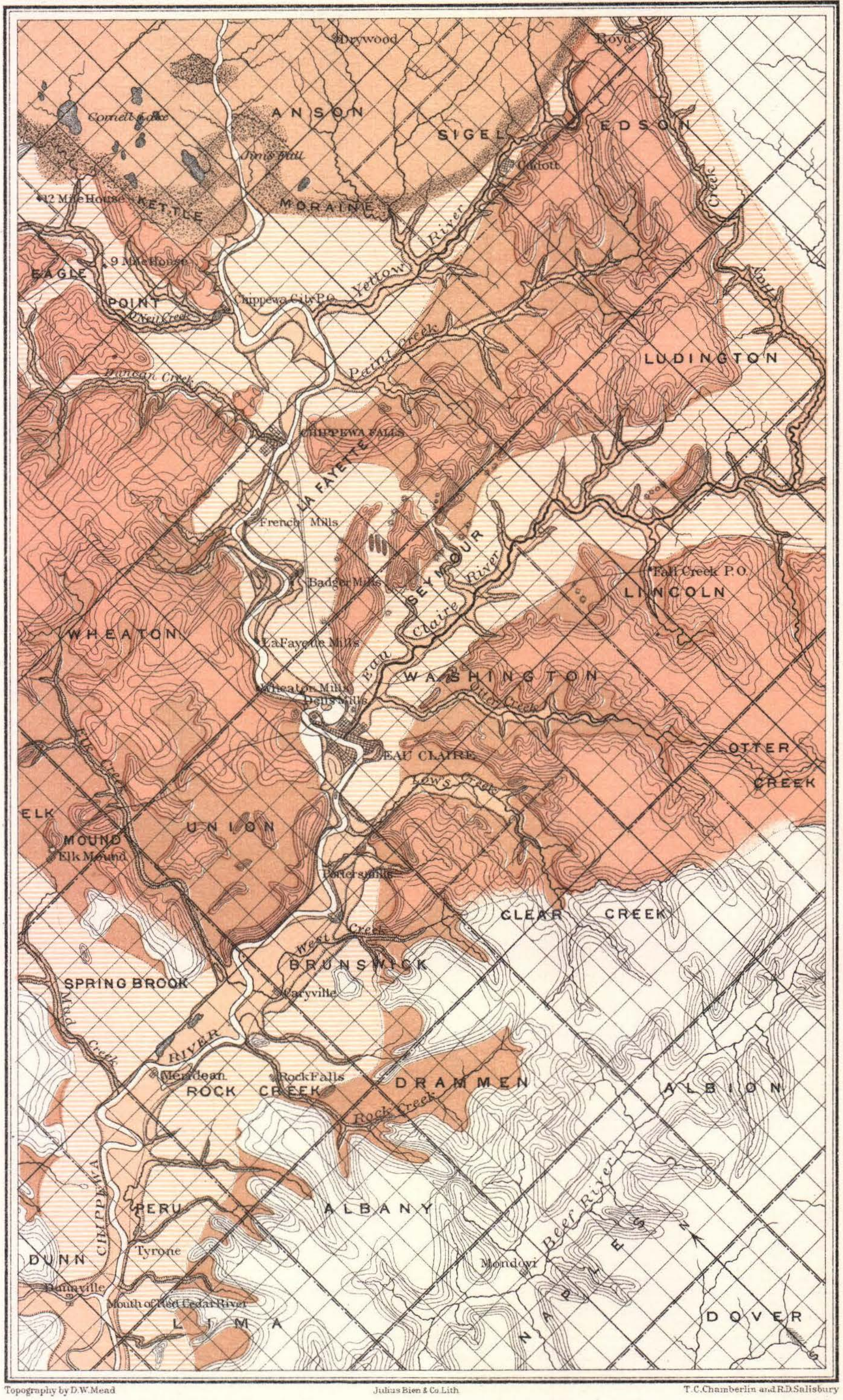
TERRACES OF THE GLACIAL FLOOD DEPOSITS.

We have heretofore remarked that the floods that issued from the border of the glaciers of the second epoch bore detritus down the valleys that led across the driftless area and filled them up to depths of 100 feet, more or less, above their old channels, giving to the valleys broad, flat bottoms. Into these the streams have since carved systems of terraces. The extent to which this carving has proceeded varies both in depth and in width, and the resulting terraces vary accordingly. In the Mississippi Valley the lateral action of the stream has been sufficient to almost entirely remove the glacial deposit from bluff to bluff, except in embayments and in the enlarged mouths of tributaries. There is, therefore, no continuous or conspicuous system of terraces bordering the Mississippi. The disconnected remnants show only one prevalent plain, the old flood plain of the retiring glacial epoch. Below this there are occasional lower terraces, but we have not discerned any prevailing subordinate system. They seem to us to be local phases of degradation. The upper terraces representing the glacial flood plain are about 100 feet above the present river, where they enter the driftless region from the northwest; where they issue from it at Savanna, Ill., they are about 50 feet above the water level.

A similar general statement may be made respecting the valley of the Wisconsin River, except near the point where the Kettle moraine crosses it, near Prairie du Sac. Here the river hugs the left or southern bluffs, and the broad overwash plain of the moraine lies on the right, about 90 feet above the present water surface. At the point of its origin this old plain still occupies nearly the entire width of the valley, but shortly after passing the moraine the present river has succeeded in re-excavating almost the entire width of its broad bottoms.

Along the Chippewa River the post-glacial excavation has been deeper but less in lateral extent, resulting in the development of a very fine series of terraces. The flood plain issued from the moraine at an elevation about 990 feet above tide.[1] At Chippewa Falls, the upper terrace plain is about 913 feet. Between Chippewa Falls and Eau Claire it ranges from 913 feet down to 885 feet, which is its elevation at the lat-

[1] This and the following observations on the elevation of the terraces of the Chippewa are from aneroid measurements made by Mr. D. W. Mead.



Topography by D. W. Mead — Julius Bien & Co. Lith. — T. C. Chamberlin and R. D. Salisbury

GLACIAL FLOOD PLAIN OF THE CHIPPEWA RIVER.

Moraine and later Drift | Earlier Drift | Glacial Flood Plain | Tributary Plains | Terrace System

Scale 6 miles = 1 inch. Contour-interval, 25 Ft.

ter locality. From this point to Durand, 27 miles below, it declines from 885 feet to 735 feet. At its mouth its elevation is probably about 680 feet, though we have no trustworthy measurement. The old flood plain, therefore, from its head to Durand declines, in the distance of 42 miles, 255 feet, or 6.07 feet per mile. The total decline to the Mississippi, assuming that it there had the same elevation as the terrace opposite its mouth, is 310 feet, or 5.25 feet per mile. The height of the upper terrace at Chippewa Falls, above the present water level, is 65 feet; at Badger Mills it is 80 feet. At Eau Claire, below the falls, it is 130 feet; at Meridean, it is 90 feet; at Durand, 63 feet. Its greatest elevation occurs at Eau Claire, from which it appears that the present stream declines more rapidly from the origin of the flood plain to Eau Claire than the ancient one, a fact which is mainly due to the rock barriers of granite at Chippewa Falls and of sandstone at the Upper Dalles and at Eau Claire, which have retarded the cutting down of the present stream in this portion of its course. From Eau Claire to the mouth of the Mississippi, the present flood plain declines less rapidly than the ancient.

Between the granite barrier at Chippewa Falls and the moraine, the system of terraces embraces four members which frequently merge in one that is not sharply or constantly developed. Below Chippewa Falls the system changes, and three well defined terraces are developed at 35, 55, and 80 feet, respectively, below the glacial flood plain. The next rock barrier, in section 16, Lafayette Township, introduces another change, giving only one well defined terrace 25 feet beneath the old flood plain, while below there lie a rambling series of minor ill-defined platforms. A constriction at Lafayette Mills cuts off the entire series, below which only two are developed, the lower one being about 40 feet below the flood plain. Below the Narrows at Eau Claire three terraces are well developed, the first one being 50 feet below the glacial flood plain, the second 80 feet below, and the third 95 feet. Below a constriction in section 25, Eau Claire Township, a system embracing plains 25, 70, and 90 feet, respectively, below the ancient flood plain is developed. Below this, the several terraces are quite largely lost in a single slope from the glacial to the present flood plain. The maps of Mr. Mead clearly show that the successive systems of terraces here owe their origin to the barriers the present stream encountered in cutting down its channel. Each stayed the downward progress of the stream and caused the portion immediately above to excavate a wide plain by lateral cutting as it meandered to and fro. It appears probable that the barriers were cut across by the formation of falls which began at the lower side and gradually cut back across the obstruction. When the stream had thus cut a "stope," as miners would phrase it, across the barrier, and reached the soft detrital material above, it would rapidly trench back through this and assume a new level, where it would remain while the next stope was being cut across the barrier. In the mean time it was engaged in forming a new plain above, by meandering. We know of no reason for believing that there were special elevations of the barriers.

There is an interesting development at Eau Claire which affords a positive demonstration that the terraces of the Chippewa Valley are purely the results of excavation, and not in any sense constructive. The recent river, instead of following the main old valley, took a course across a neck of rock on the west side, and has cut its new channel entirely outside of the old valley. In its meanderings above and below, it has excavated nearly across the old valley, but a narrow neck of the old filling extends from the bluffs on the east entirely across the old valley and joins the bluff which formed the headland, across the neck of which the present stream has cut a rock channel. Essentially the same phenomenon occurs above and below, but is not so cleverly shown. A similar phenomenon occurs on the Trempealeau River, at what is known as the "Pass," which is a narrow rock gorge cut by the recent stream on the western side of the old valley, leaving a remnant of the old flood plain stretching across the former valley entirely intact.

In the Black River Valley the old flood plain projects, first from the one side and then from the other, in such a way as to form interlinking teeth, as it were, that leave no ground for doubt that the entire valley was completely filled. On the Wisconsin River, immediately below the moraine, nearly the entire valley on the north side is filled with flood deposits, the present stream occupying a narrow gorge upon the southerly margin which is so manifestly a post-glacial cut that the filling of the whole valley cannot be a matter of doubt.

In the Rock River Valley, just below Janesville, the stream passes through a rock valley lying on the west side of the old valley, which it here entirely abandoned, leaving for several miles the glacial flood plain intact. At several points below, the stream closely hugs the western side and encounters the rock margin of its old valley, leaving the deep ancient gorge filled essentially from bluff to bluff to a known depth ranging from 150 to 350 feet and a probable maximum depth of 400 feet.

Next to the Chippewa River, the terraces of the Black River are best developed, but they have not as yet been critically studied. On the Trempealeau River there are also fine terraces carved mainly from the finer fluvial constituents, this valley apparently not having been one of the main channels of glacial discharge. On the west side of the Mississippi the Zumbro, in Minnesota, and the Turkey River, in Iowa, are attended by fine gravel terraces, both of these streams apparently having been avenues of discharge for the glacial waters of the second epoch, and thus became filled with gravel trains suitable for the subsequent carving into the terraces. Nearly all the other tributaries of the Mississippi and the Wisconsin have a system of one or more terraces, excavated from the silt plains that filled those rivers near their mouths, owing to the building up of the bottom of the main arteries and the ponding back or slackening of the inflow of the tributaries.

The great alluvial systems of the driftless region and the adjacent district are unmistakably connected with the second glacial epoch, and the higher systems of sharply cut terraces were excavated from plains which had their origin during that epoch. None of the valleys that existed before that epoch and were not filled during it present any sharply defined terrace system. None of the old drift furnishes a substratum out of which a sharply defined terrace system has been excavated. This appears to be mainly due to the antiquity of the earlier epochs. The lapse of time since the valleys were exposed to excavation has been such that lateral erosion has rounded down and deeply dissected the borders of the valleys. There are not wanting obscure evidences of old terraces, but they are only the rounded remnants of a nearly obsolete system. Nowhere have they the sharply angular edges nor the steep descent of the newer system. From somewhat wide observation we entertain the confident belief that when the respective ages of the terrace systems of the Quaternary period shall have been determined it will appear that all of the clean-cut, sharply defined alluvial terrace systems were constructed from the later drift and the Champlain deposits, and that no system of drift terraces as ancient as the earlier glacial epoch has failed to suffer degradation to so great an extent as to lose its sharp definition and become unobtrusive. The detection of these will be the work of critical observers alone.

CHAPTER VI.

HISTORY AND GENESIS.

SEQUENCE OF EVENTS.

The theme which might be regarded as the central subject of our paper remains untouched: the origin of the driftless region. The discussion of this question is not, however, the prime object of this paper. In our judgment, the vital elements of the true cause of the driftless region were made known some years ago by Winchell, Irving, and the senior writer of this paper. The topic, however, needs supplementary discussion, as well as some consideration of its relationship to the successive stages of glaciation, of which our knowledge has since been brought into clearer definition. In this paper we have been seeking the light which the driftless region throws upon the successive episodes of glaciation and the conditions which were potential during them, rather than the propagation of the doctrine of its origin.

Preliminary to this question of origin, it may be serviceable to call up afresh the sequence of events which are expressed in the phenomena of the region and of the bordering drift tracts.

Antecedent to the epochs of glaciation there had been a prolonged interval of surface erosion, during which the face of the country was sculptured deeply into systems of hills and dales in complete subservience to the familiar methods of drainage erosion.

1. The first event of the ice age, of which we have yet found sufficiently clear testimony to demand consideration here, consisted of an extension of the glaciating agencies from the north around both sides of the driftless area and their coalescence below it. The stream on the west reached 250 miles below it and the stream on the east 325 miles. To this stage, as we now interpret it, is to be referred the older drift sheet which forms the border on the southeastern and northern sides of the area. We also regard the attenuated pebbly border upon the west side as contemporaneous with this. Of this relationship, however, we have not that specific and definite evidence which could be desired. As we have before indicated, the lithological character of the pebbly drift border is similar to that of the lowermost member of the drift series of Iowa, as determined by McGee. This is subordinate to the upper till, which is held by McGee to have also a pebbly border and to be essentially contemporaneous with the loess. Now the loess deposit overlaps the southern portion of the old drift on the eastern

DIAGRAMMATIC MAP OF DRIFT CURRENTS ADJACENT TO THE DRIFTLESS AREA

Observed Striae. General, and in part Hypothetical, Course of Currents.

Striae in the northern part probably formed at a late stage. The currents there may have been less complex than indicated.

border of the driftless area and presents indications of an intervening interval; so that the most rational view seems to us to be that the lower drift on the Iowa side, including the pebbly border, is the equivalent of the older member upon the east side.

The agency which deposited the older drift upon the east side and in like manner spread at least a portion of the extended drift sheet upon the west side was, we are convinced, land ice. We will not here enter into the discussion of the evidence in support of this opinion, but simply refer to the description of the older mantle of drift on the southeast side of the driftless district, where it is found to terminate in a way that seems to us entirely incompatible with any hypothesis of glacio-natant deposition. The constitution and distribution of the material are such as we esteem to be peculiarly the result of glacier action as distinguished from the deposits that we conceive may be formed by floating ice. Striæ of the glacier type occur west of Beloit, Wis., pointing directly toward the drift margin and within 25 miles of it.[1]

The attenuated pebble border, however, does not possess characters which we can attribute to glacial production. The exceedingly attenuated edge, the paucity of glacial clays, the want of notable erosion of the glacial kind at any observed point, and the several other characteristics brought out in the description before given, seem to us to exclude direct glacier action. We believe the deposit was formed by the aid of floating ice in a body of water fringing an ice lobe which lay to the west. Evidence of such an ice lobe we find in the character of the deposits which certain portions of the drift-mantle of the territory to the west present and in the planation and striation of the surface at certain points. We have at times entertained doubt as to the direct glacier origin of some of the outer portions of the older drift, and, under the promptings of this skepticism, a few months ago one of us visited the southernmost known locality of striation in that quarter—that in the southwestern corner of Iowa, previously described by Dr. C. A. White[2]—with the especial purpose of determining, if possible, whether it was truly the work of a glacier or of some other agency. The surface was found planed to a uniformity and smoothness and engraved with both coarse and delicate lines of a straightness and steadiness of course and a delicacy of execution that do not characterize the work of any other agency with which we are familiar. Viewed in the light of the presence of local material in the drift, and of the very significant distribution of quartzite erratics, long since pointed out by Dr. White,[3] and of the observations of striæ by Hayden, Aughey, and Todd, in Nebraska, there seems a decided preponderance of evidence in favor of the glacial occupancy of the western region, at least as far south as the limits of Iowa. That this lobe may have been bordered more or less

[1] I. M. Buell, Transactions Wisconsin Academy of Sciences, 1876-'77, p. 229.
[2] Geology of Iowa, Vol. I, 1870, p. 94.
[3] Loc. cit., pp. 87-91.

extensively on other sides, as we suppose it to have been on the east, by marginal waters, is not improbable. Professor Mudge describes erratic pebbles in Eastern Kansas as being scattered as far south as 38° north latitude, while the bowlders only extend to 38° 50′.[1] From a reconnaissance of the region, we are of the opinion that no glacier extended beyond the limit of bowlders, as we saw nowhere specific glacial evidences. Our observations in Missouri are of like import.

2. The second salient event which we recognize was the deglaciation of the region to such an extent as to permit the growth of vegetation over the surface; not, as it would appear to us, that it was a great forest-clothed region, but still a tree-covered one.

3. The third leading event was a reglaciation, evidence of which has been developed by the geologists of Iowa and Minnesota previously cited. This spread over the region a mantle of till deeper than the earlier one. Its action was such as to bury beneath its border the old soil, peat beds, trees, and other vegetal relics of the preceding episode of deglaciation. To what precise extent the vegetation was buried by being overridden by the ice, and to what extent by glacio-natant agencies, remains with us yet an open question. Mr. McGee maintains that the abrupt border and singular distribution of the loess in Eastern Iowa is evidence that it was formed contemporaneously with the closing stages of this glacial episode, and, one of us having cursorily inspected some of the more significant localities of the region under his guidance and having studied other portions independently, we are inclined to acquiesce in his opinion, though, as heretofore indicated, we are unable as yet to frame a fully satisfactory conception of the precise conditions which would permit a deposit of silt of so wide vertical range without involving also a greater deposition of pebbles, bowlders, and clay through the same agency as that which spread out the loess. Pebbles do occasionally occur in the loess, and one of us observed a bowlder 4½ feet in diameter, which was found wholly imbedded in it. The loess does, also, in Southeastern Iowa, according to McGee, graduate imperceptibly downward into stony clays. It also graduates laterally and vertically into clayey deposits in Southwestern Minnesota, as earlier observed by Winchell.[2] Something of the force of the difficulty is relieved by these considerations, yet it remains remarkable that the loess should be so singularly assorted under such conditions.

4. A long period of freedom from glaciation appears to have followed the epoch of the deposition of the second till and loess, involving extensive erosion and the lifting of the upper portion of the basin to the extent of 800 or 1,000 feet. The evidence of this is found in the low altitude and gentle slopes which must have prevailed when the loess was deposited along the great streams from Nebraska to In-

[1] Fourth Agricultural Report and Census, Kansas, 1875, p. 109.

[2] Geological and Natural History Survey of Minnesota. Sixth Annual Report, 1878, p. 105.

diana and southward to the Gulf; and in the higher elevation which made it possible for the later glacial streams to flow with rapid, pebble-carrying currents at altitudes 700 feet below the summit of the loess. We believe this to have been the chief interglacial epoch.

5. Following this interglacial epoch came the incursion of ice which pushed up at its edge the Kettle moraine and sent coursing down through the valleys its gravel-bearing streams, filling them and spreading out broad flood plains, the groundwork of subsequent terracing. The agency, in this instance, we hold to be demonstrably land ice. The phenomena are too sharply defined and too pronounced in character to admit of doubt on the part of competent investigators who will familiarize themselves upon the ground with the precise details of all the varied phenomena. We believe that all who have critically studied the region are convinced beyond doubt of the glacial origin of the Kettle Range and the glacial occupancy of the territory lying back of it.

6. There closely followed this second glacial occupancy a succession of stages of deglaciation and readvancing ice. These, while they are phenomena of great interest, do not enter essentially into the problem before us.

7. Subsequent to the cessation of the glacial floods, the streams carved the flood plains into terraces.

According to General Warren, Lake Pepin, an enlargement of the Mississippi River, is now 60 feet deep. It has undoubtedly been somewhat silted up since it came into existence, so that its bottom was once lower than now. There can be little doubt that Lake Pepin owes its origin to the barring up of the channel at the mouth of the Chippewa by the excess of sand poured in by that tributary, as maintained by General Warren. It follows that the valley must have been previously excavated to the present depth of the lake, plus the amount to which the latter has been filled. This has been done since the glacial retreat, apparently at a stage immediately antecedent to the present.

ORIGIN OF THE DRIFTLESS REGION.

What were the conditions that enabled the driftless area to escape the glaciation that repeatedly intruded itself upon the surrounding country? In the very fact that the glaciation of adjacent regions was repeated, we have an element of significance. The immunity from drift was manifestly not due to some fortuitous condition that chanced to direct the glacial incursion. The cause was a constant one, influencing each of the episodes in which the region was threatened by ice. The cause must, therefore, have been a geographically fixed one. In our introduction, we cited the fact that the region is not a conspicuous elevation, but rather the opposite.[1] Its average altitude is less than the average altitude of an equal area lying north or west, while it is not notably different from that east and south. Its driftlessness cannot, therefore, be attributed to its own

[1] Irving, Geology of Wisconsin, 1877, Vol. II, pp. 608-611.

elevation, unless that elevation were very different from the present. The facts which we have above given seem also to withhold us from postulating a special local elevation through the glacial period; for in the first subepoch we found evidence of a relatively lower altitude than at present in the attenuated pebbly drift along its western border. In the second subepoch we found similar evidence in the loess, spread even more extensively over the western border. In the later epoch we found the glacial rivers pouring freely down from the edge of the ice across the driftless tract. It seems to us, therefore, futile to seek for an explanation in the altitude of the region itself.

But if we extend our view and take into consideration the topography of the whole territory involved, the most important elements of the true explanation will, we think, be found. In 1877, Professor Winchell called attention to the fact that the driftless area lies in the lee of the elevated territory of Northern Wisconsin and Michigan, which, he maintained, acted as a wedge, forcing the ice aside and so protecting the driftless region in its rear.[1] In the same year Prof. Irving called attention to the fact that the great valleys of Lake Superior and Lake Michigan lie in such a relationship to the driftless area as to tend to divert the glacial streams to the right and left, and this, in connection with the highlands lying between the lakes, turned away the ice from the driftless region.[2] Two years anterior, the senior writer had entertained and expressed to his associate, Mr. Strong, who was then engaged in the investigation of the lead region lying in the heart of the driftless district, an opinion respecting the origin of the phenomenon which was closely similar to that of Professor Irving. In 1878 the subject was more fully discussed by the senior writer,[3] drawing forth the idea that the combined influence of the heights of Northern Wisconsin and Michigan in crowding aside the ice and of the Great Lake troughs in leading it away and prolonging its divergent courses still left a troublesome residuum unexplained. The heights themselves are manifestly incompetent, since the ice, according to the analogy of existing streams in Switzerland, should have wrapped around them and coalesced immediately below, as the glacier Telèfre does around the Jardin.[4] The prolongation of the basins undoubtedly counteracted this tendency, and led the stream on the left southward into Illinois and on the right southwestward into Minnesota. But these influences combined still permitted an ice stream, even in the later epoch, to override the highlands south of Lake Superior, and to creep down the southerly slope directly toward the driftless region for a distance of 75 miles in the later epoch and 100 miles in the earlier. Here, advance was stayed on the southerly slope in a plane region, without any obvious obstruction or barrier of any kind. The staying of

[1] Fifth Annual Report Geological and Natural History Survey of Minnesota, 1877 p. 36.

[2] Geology of Wisconsin, Vol. II, 1877, pp. 608–611, 632–634.

[3] Annual Report Wisconsin Geological Survey, 1878, pp. 21–32.

[4] Report Annual Wisconsin Geological Survey, 1878, p. 21.

this stream was attributed to the wasting influences to which its environment subjected it. The thinning of the ice, caused by the diversion of the great streams through the lake troughs and by the interposition of the heights, led to a retarded, feeble flow and a relatively increased wastage. The difference in the thickness of the ice streams that passed over the heights and through the adjacent valley troughs was, approximately, 2,000 feet, a difference that may well have been effective.

This estimate needs to be qualified. It involves the assumption that the upper surface of the ice was essentially plane over the Superior region and that lying immediately north. Now, if this region lay within the zone of glacial accumulation the probabilities are that such would not be the case, for the freer flowage through the valleys would tend to draw down the surface above and immediately beyond them. Névés are concave in valleys and basins. On the other hand, if the region lay within the zone of glacial wastage, the opposite was probably true; or the wastage of the more slowly flowing, thinner portions on heights would be *relatively* greater than that of the deeper massive valley currents, while the free flowage of the latter would supply the wastage more promptly by new inflows from the north. It is a general law, illustrated in numerous instances in Alpine glaciers, that the ablation surfaces are highest in the central axes of the glaciers, where the flow is freest.

Another qualification of opposite import lies in the fact that these troughs do not extend indefinitely southward, but shallow out, and this shallowing must have tended to retard the freedom of onward flow.

We judge that the above influences combined would have increased the difference in thickness between the valleys and the heights.

But full satisfaction is not rendered by the hypothesis as it thus stands. It does not fully explain the course of the currents on the west side of the area. While it does not seem strange that the current which passed through the trough of Lake Michigan should have kept straight onward over the smooth plains of Illinois, merely deploying to the right and left, it is remarkable that the stream which passed by on the west side should have had its main channel along what is now a relatively elevated tract lying between the two great rivers of the region, the Missouri and the Mississippi. Why did it not follow down the Mississippi Valley?

It seems probable that this strange course was due to a relative depression of the region occupied, evidence of which we think we have found (1) in the pebbly deposits of the first glacial stage, (2) in the loess of a subsequent one, and (3) in the phenomena of unequal elevation of the opposite sides of the glaciers of the later epoch in the Minnesota Valley and on the plains of Iowa, to which attention was directed in the Third Annual Report of the United States Geological Survey, 1882, pp. 390, 391. If it be true, as we have suggested, that the depressed condition of the plains of Nebraska and adjacent regions which prevailed in the Pliocene epoch had not entirely disappeared, the course of glacial movement appears less remarkable. That the slope of that region was less, shortly before the glacial incursion, may be plausibly inferred from the character of some of the valleys. The James River Valley of Southern Dakota is a broad, flat-bottomed plain, 60 miles in width, bordered on the east by a steep acclivity of from 600 to 800 feet and on the west by a similar but less uninterrupted ascent. It bears evidence of being a valley of erosion excavated from the Cretaceous strata. The presumptive agent was a widely meandering stream, which had approximately reached a base level of erosion. Such a base level seems to imply either a low elevation above the surface of the sea or a barrier along its line of outlet. In the absence of a known barrier the former seems to be the probable cause. The valley of the Red River of the North, the Great Ree Valley, and others of the region, present phenomena harmonious with this interpretation. On the other hand, the channels of the Mississippi River and its tributaries are relatively narrow and cañon like, implying excavation under different conditions. Dr. G. M. Dawson in several papers presents evidence which he interprets as indicating a depressed condition of the Northwestern plains during the deposit of the drift. While we do not coincide in all the features of his interpretation, we accept the evidence of relative depression as at least measurably valid.

If this view of the relatively low elevation of the region adjacent to the old Pliocene basin is correct, the course of the glacial currents west of the meridian of the driftless area becomes intelligible.

The foregoing seem to us the more immediate influences that diverted the glacial currents from the driftless area. But our view is yet too narrow. There lurks beneath it the suspicion of inadequacy. A broader survey of the field reveals auxiliary influences. If the highlands and flanking valleys immediately adjacent to the unglaciated area were influential in directing the glacial current, highlands and valleys flanking these presumably lent their aid so far as they were favorably situated.

We assume—and will assign reasons for the assumption later—that the great area of dispersion lay to the distant north or northeast, giving a broad zone of waste and of neutrality in which movement was controlled by conditions of topography and ablation.

Appeal has already been made to the influence of the highlands immediately north of the driftless area and to that of the valleys of Lakes Superior and Michigan, which flank it. To the east of the Lake Michigan trough lay the capacious valley of Lake Huron, flanked by Georgian Bay. There is strong evidence that these valleys diverted the glacial streams southward, in the retiring stages of glaciation at least, and presumably at all stages. This is shown both by striation and by transportation. Copper, presumed to come from the Lake Superior region, has been found in Eastern Michigan and even in Ohio. In the remarkable bowlder belt of Logan, Champaign, Miami, Montgomery, and Preble

Counties, Ohio, and Wayne and Randolph Counties, Indiana, are numerous peculiar greenish quartzite bowlders not common to the general drift. Professor Irving has identified specimens of these as derivatives from certain quartzites of the typical Huronian region, north of Lake Huron, samples in his collection being indistinguishable from the erratics collected by one of us. While it is possible that both the native copper and these quartzites may have had an origin farther to the eastward, these instances, taken in connection with a wider class of evidence, leave little room for doubt that the basin of Lake Huron determined a southerly movement of the ice current, and thereby rendered collateral aid to the Michigan basin in diverting the broad stream east of the unglaciated island.

On the other hand, immediately northwest of Lake Superior, lies a high northeast and southwest trending highland belt, beyond which is a relatively low tract. Farther away is the broad depression through which the Nelson and Churchill Rivers drain a large portion of the northwestern basin. The highest land of this region is said to lie immediately northwest of Lake Superior and trends southwesterly parallel with it. The mer de glace, therefore, flowing southwesterly from the Hudson Bay region found freer passage along the more westerly courses, and this less obstructed flow obviously aided the divergence of the currents to the right. The broad open valleys of the Red River of the North and the James River, aided by the somewhat lower elevation which they probably then had, doubtless led the currents southward through these freer passageways, until they had reached the central latitudes of Nebraska and Iowa. Here the southeasterly slope which seems there to have then obtained, as now, caused them to curve easterly around the driftless region and coalesce with the Lake Michigan stream which had spread itself upon the plains of Illinois.

These collateral agencies of diversion must have greatly relieved the force of the invasion which the immediate barriers of the driftless area encountered, and which, through this and other aid, they were enabled to successfully divert. Meanwhile the meager, unfavored stream that came over the highlands above the area crept slowly down the southerly slope and was met by the wasting winds from the iceless tract.

The zone of waste.— In the above discussion we have taken no account of possible glacial accumulation as influencing the course of the ice currents. We have considered the problem as though it involved only the area of glacial waste. In postulating so broad a zone of ablation we are probably almost without support among American glacialists. Judging from the literature of the subject, the prevailing opinion has been that the zone of glacial accumulation extended southward nearly to the border of the ice, and that both the lobation and the peripheral currents were much affected by local accumulation. Against this view one of us has heretofore contended.[1] The recent observations of Baron Nordenskjöld,

[1] Sixth Annual Report Geological Survey of Wisconsin, 1878, pp. 27-29.

on the ice fields of Greenland, very strongly confirm our convictions.[1] At the extreme limit of his incursion upon the ice field he reached a tract of slushy snow and water which was manifestly the neutral border between the zones of waste and growth, for that season at least. Throughout his journey, except in the last few miles, he encountered a surface covered with kryokonite and pitted by superficial melting, which had manifestly removed not only the last season's snow but was working its way into the more ancient ice. On the other hand, the Laps who advanced into the interior beyond found unmelted snow prevailing and were driven back for want of water, indicating that they had reached the true névé. From these important observations, it is clear that here at least the neutral zone lies approximately 100 miles distant from the edge of the mer de glace. But it must be noted that here the glacier does not terminate upon a plain by simple subaërial waste, but discharges itself into the sea. If it were extended until consumed by melting and evaporation in situ, the zone of ablation would be considerably increased.

Besides this, it is quite certain that the breadth of the zone of waste must bear a certain relationship to the area of accumulation. While this ratio undoubtedly varies through some considerable range, it is quite irrational to suppose that the area of wastage of a greater mer de glace is less than that of a smaller one under similar conditions. The width of the tract of waste of the Greenland glacier is many times as great as that of any Alpine glacier, and we are certainly bound to recognize the probability that the zone of waste of the great Quaternary glaciers was more extensive than that of the relatively limited Greenland glacier of to-day. Hence we feel that we are reasoning quite within bounds when we assume that the wastage tract of the Quaternary glaciers lying adjacent to the driftless area was not less than 150 miles in width. If we draw a line from the north border of the driftless area backward that distance it reaches well out upon Lake Superior. If it be drawn eastward from the east side of the driftless region it reaches beyond the center of Lake Michigan. If it be drawn westward from the western edge of the unglaciated area it reaches the Missouri watershed, or nearly half across the western belt of drift. Now, since there must have been a tract of waste on each side of this prolonged lobe, it is manifest that there could have been little or no zone of accumulation on any portion of it, unless the zone of waste were narrower than we have estimated. In 1878 one of us maintained that the most extreme view permissible concerning the prolonged glacial lobes was that a belt of accumulation lay along their central axes.[2] To permit this in the case of the broad lobe on the west side of the driftless area, giving it every benefit of doubt as to its

[1] Nature, November 1 and 8, 1883. Science, December 7, 1883, pp. 733–737. The final computations of Baron Nordenskjöld are not at hand at the date of writing, and the accompanying estimates are based on his preliminary results, which may require modification.

[2] Sixth Annual Report Geological Survey of Wisconsin, 1878, pp. 27–29.

width, the zone of waste could not have been essentially greater than that of the glacier of Greenland to-day, as estimated from Nordenskjöld's observations.

We are not without other evidences of the correctness of these conclusions. In the study of one of the great lobes of ice of the second epoch, somewhat more than a decade ago, one of us determined a law of divergent flow from the lobe axis, which, while in some measure perhaps suggested before, had never been shown to have the pronounced expression which it was then demonstrated to possess in the case of the Green Bay ice lobe, and which has since been found to be exemplified in other great ice lobes to such an extent as to become a reliable basis on which working hypotheses may be safely constructed. This divergence of flow obtained in the lobation of the ice of the earlier epoch, as well as of the later, though not so clearly demonstrated because of the relative feebleness of the ice action and consequent meagerness of striation and similar demonstrative evidences.

Now, while it appears probable that the prolongation of the glacial lobes and the development of the axi-radiant glacial movements would be favored by snow accumulation along the crest of the lobes, yet, if this reached a degree of effectiveness sufficient to furnish any notable proportion of the glacial material and so to control the currents, it would divert to the right and left, the ice advancing from the north carrying with it the northern erratics. These would then appear along the sides of the lobe near where it became differentiated from the common mer de glace, but not in the terminal portion. The bowlders there should be mainly local or semi-local. But observation shows that the northern erratics have been carried along the axial belts of these lobes from 300 to 800 miles. Indeed, these northern erratics constitute a very large element of the bowlders and pebbles of the extreme terminal lobes of drift deposited by the apices of the ice tongues. We infer, therefore, that the local accumulation on the crest lines of the glacial lobes never made notable contributions to the material of the glaciers. It may have been sufficient to partly or wholly counteract wastage, and perhaps even slightly exceed it in their northern portions near the great mer de glace, but we think it could not have influenced glacial movements to any such extent as to require recognition among the effective agencies that determined the driftless area. As we interpret the glacial movements and the distribution of erratics, they indicate that the effective area of glacial accumulation which controlled dispersion lay north of the Great Lakes, and such local accumulation as occurred south of this was determined by the glacial lobes themselves, instead of determining them.

This position we conceive to be strengthened by the fact that the glacial prolongations followed valleys and not heights. Local accumulation, had it been an independent agency, should have been most effective on the highlands and not in the valleys, but the evidence is overwhelming that in the interior United States the valleys and basins were the theaters of most active glaciation while the heights and plateaus were avoided. To us this is equivalent to proof that the tracts of glacial occupancy were determined by the combined laws of quasi-fluidal movement, conditioned by topography, and of glacial wastage, conditioned by climatic influence.

Climatic influences.—We have considered the topographic influences determining the quasi-fluidal movements. It remains to inquire whether there were any special climatic influences that favored the wastage of the currents which threatened the driftless area, on the one hand, and retarded the ablation of the prolonged streams on the other. We have been able to discern none inherent in the region. Neither rainfall, cloudiness, nor winds are notably greater or less in this area than in the adjacent ones. The limited and imperfect observations that have formed the basis of the climatic charts heretofore constructed show local variations, but these are not conterminous with the area, nor, what is really crucial, conterminous with *the wastage area in which the threatening glaciers were consumed.*

The law of self-perpetuation of climatic conditions was doubtless effective. Just as there can be little doubt that the ice-clad regions increased the snowfall upon themselves and tended to self-perpetuation, so, doubtless, the ice-free area, by warmth, and therefore relative drought, fought back the advancing ice. At the time it was most threatened—when the ice seems to have completely surrounded it—a special action, we have thought, may have come to its aid. The prevailing winds—assumed to come from the southwest, as now—as they encountered the ice belt on the west and south of the area were freed of their moisture by the cooling effects (1) of the ice and (2) of their ascent of the west slope of the glacier. As they descended on the east side they regained their capacity for moisture and were relatively dry and absorbent winds, and the extent of the area may not have been sufficient to again saturate them before they impinged on the ice of the northern and eastern borders.

Whatever of self-propagation and self-preservation may have arisen from these or other similar influences was manifestly secondary, and only became efficient after the primary causes had developed the essential features of the phenomenon. They were not originating, but only intensifying agencies.

Under the general conditions that determined the glaciation of the interior and under the laws that control movement in the zone of glacial wastage, it seems clear that the dominating agency was topographic. To this other influences were but auxiliaries.

Diverted by highlands, led away by valleys, consumed by wastage where weak, self-perpetuated where strong, the fingers of the mer de glace closed around the ancient Jardin of the Upper Mississippi Valley, but failed to close upon it.

THE QUANTITATIVE DETERMINATION OF SILVER

BY MEANS OF

THE MICROSCOPE.

BY

JOSEPH STORY CURTIS.

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THE QUANTITATIVE DETERMINATION OF SILVER BY MEANS OF THE MICROSCOPE.

By JOSEPH STORY CURTIS.

THE PLATTNER SCALE.

In Plattner's Probirkunst[1] a method of assaying silver ores by means of the blow-pipe is described with which most assayers are familiar, although very few of them make practical use of the process. The only portion of this method with which the present paper has to deal is that which describes the manner of determining the weight of small beads of silver by measuring their volume. Harkort was the first who applied this method, and Plattner followed his plan when he constructed the scale which is explained in his work on assaying with the blow-pipe.

The method was the following: An ore was selected which contained 3.48011 per cent. of silver. This was carefully assayed by means of the muffle and the blow-pipe. The resulting bead of silver, after the different assays were found to agree, was taken as a standard in constructing the scale, which was made as follows: By means of a sharp engraving tool a line, A B, was drawn on a polished strip of ivory (see Fig. 49), and another line, *a b*, was drawn parallel to it. From the point *a* a line, *a c*, was drawn which diverged from the line *a b*, the distance *b c* being about equal to the diameter of the bead. Parallel to the line A B still another line, C D, was drawn. The line A B was divided into fifty-two equal parts. The distance between the points *d* and *e* was found, when exactly measured, to be equal to the diameter of the bead.

The following is the formula by which the values of the different divisions on the Plattner scale are calculated. Let:

$W =$ weight of a given bead (in this case 3.48011 milligrams, the blow pipe assay ton being 100 milligrams).

$D = de =$ diameter of the same.

$L = ad = ae =$ distance of the same from the 0 point.

$x =$ weight of another bead the diameter of which is $d = fg$

and $l = af = ag =$ distance of this bead from the 0 point.

[1] Plattner's Probirkunst mit dem Löthrohr, by Theodor Richter, Leipzig, 1865.

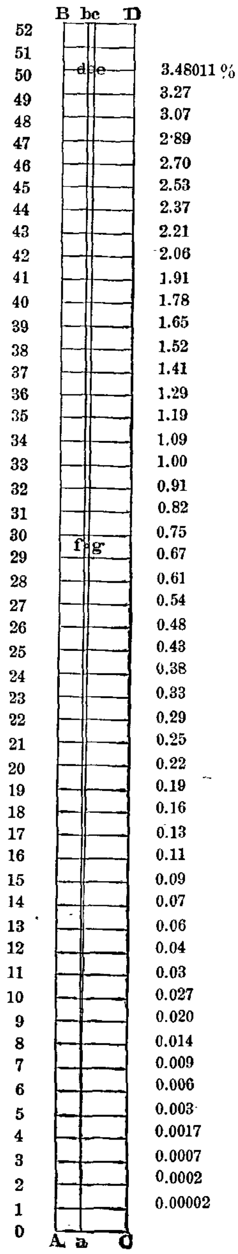


FIG. 49.—The Plattner scale.

Then, $W : x = D^3 : d^3$,

also, $D : d = L : l$.

Therefore, $W : x = L^3 : l^3$

$$x = \frac{Wl^3}{L^3} = \frac{W}{L^3} l^3.$$

W being equal to 3.48011 milligrams and L equal to 50, the constant $\frac{W}{L^3}$ becomes 0.00098. If, therefore, the cube of the distance of any of the divisions of the scale from 0 or *a* is multiplied by the constant 0.00098 the value for that division is obtained.

The measurement of beads of silver by placing them between two converging lines is attended with a great deal of difficulty as well as inaccuracy, for several reasons. In the first place, no matter how perfect the cupellation, there will always be more or less bone ash adhering to the silver beads, as can readily be seen upon examining them under the microscope. This bone ash often prevents the placing of the bead in the proper position, namely, on the flat side, and adjusting on the flat side is an indispensable factor of good measurement, as will be shown hereafter. Again, pushing the bead by means of the point of a knife, or other instrument, up and down and from side to side between two converging lines until its circumference is exactly tangent to both of them, is an operation which is not only slow and tedious, but one the accomplishment of which, with anything like speedy results, requires more skill than most assayers possess. The inaccuracy of such measurements is due to several causes, one of the principal being the impossibility of arranging the bead exactly tangent to the two converging lines, no matter how much care is taken. This is true even when a magnifying glass of considerable power is used. To obtain accurate measurements it is also necessary that the point of contact of the line and the circumference of the bead should be exactly in the focus of the glass and that the eye should be directly above this point, conditions which it is almost impossible to fulfill without the aid of mechanical appliances.

Two sources of error, but of little importance as compared with some others, are the incorrect ruling of the scale and the inaccuracies due to the shrinkage and expansion of the ivory on which the scale is drawn. Again, a perfect bead or one approaching perfection is of very rare occurrence, as an examination of a large number of beads under the microscope will easily demonstrate. The horizontal circumference of the bead approaches an ellipse in form and has a maximum and a minimum diameter (axis) as well as an infinite number of intermediate ones. If the longest diameter is measured, the calculated weight is too great; if the shortest one is used, it is too small. This applies only to very small beads, however, as even the shortest diameter of large ones gives a weight considerably in excess of the true weight. Another source of error is the fact that even beads as small as those capable of being measured on the Plattner scale are not of the same shape. The larger the bead the flatter it is, and therefore the ratio of the cubes of the diameters of two beads of different sizes will not represent the ratio of their volume. There is another inaccuracy, namely, that due to determining by guess the distance of the tangent point from zero when it lies between two divisions of the scale.

Almost all these inaccuracies were considered by Plattner and others, but they were thought to be too insignificant to affect the results. This is true of most of them, but the error arising from difference of shape between large and small beads is of too much importance to be neglected, even on the Plattner scale. This will be examined later, however. Richter says (page 39): "The use of the scale has its limits." However, he compares the sensibility of the Plattner scale with that of the balance, and finds that the scale is more sensitive and more exact than the balance up to 16 loth to the 110-pound centner (about 0.45 per cent.). It will be seen hereafter, however, that the limit of exactness lies very much below this point on the scale. Nevertheless, it has been invaluable for the blow-pipe assay of silver, which was never supposed to be anything more than approximately accurate.

Mr. Carl Foehr, in a paper contributed to the Zeitschrift für analytische Chemie, explains a method by which very small quantities of silver may be determined. It is a combination of the ordinary silver assay with the muffle and that part of the blow-pipe assay in which the bead is measured on a scale. He does not say what scale he uses, but it is presumably the Plattner, as he describes the method of Harkort.

THE MICROMETER MEASURING APPARATUS.

While occupied in assaying the country rocks of various silver districts a method occurred to me, which was partially outlined in Chapter XI of a report on the Silver-Lead Deposits of Eureka, Nevada.[1] Since this report was written, numerous experiments have been made and many new manipulations adopted which render the process of measuring not only simpler but more exact.

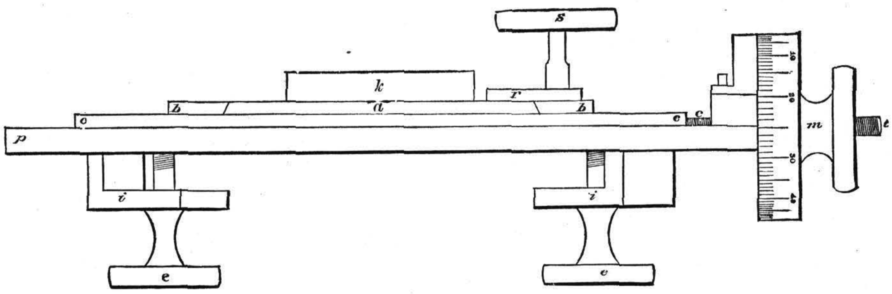
The measuring apparatus consists of a microscope with a magnifying power of from 20 to 30 diameters. This is furnished with a vertical and

[1] Silver-Lead Deposits of Eureka, Nevada. By J. S. Curtis. Monographs United States Geological Survey, Vol. VII.

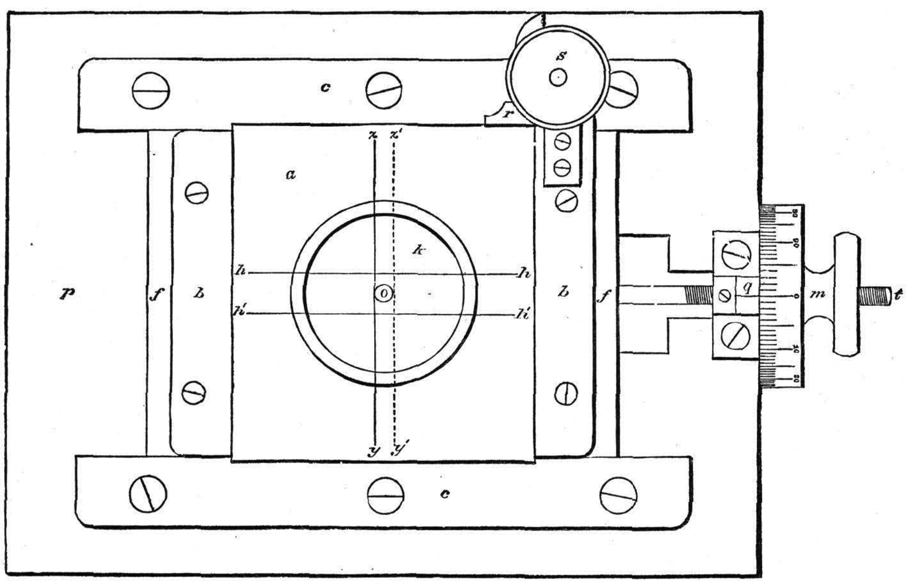
two horizontal cross hairs. The term "vertical" is used here to denote the cross hair which runs to and from the observer, and the word "horizontal" is employed to distinguish the cross hairs which would remain in a horizontal position should the shaft of the microscope be inclined. These cross hairs should cross each other exactly in the focus between the eye-glass and the object-glass in order to avoid parallax. The parallax can be almost completely prevented in another manner, namely, by the use of a cap over the eye-piece, which contains a narrow slot instead of the usual round opening. This slot in the cap need not be wider than half a millimeter, though this can be regulated according to the requirements of convenience, &c. A useful arrangement for controlling the width of this slot is two slides on the top of the cap, which can be made to approach each other by means of a screw with a right thread at one end and a left thread at the other. The slot must be perpendicularly over the vertical cross hair, otherwise the measurements will be incorrect.

Reflected light is used in measuring, and it is well to state here that one great advantage of this method of measurement is that it is unnecessary to remove the silver bead from the cupel, thereby saving time, trouble, and danger of loss. Any assayer who has ever made blow-pipe assays is aware of the inconvenience attending the removal of very small beads of silver from the cupel and of the difficulty of handling them. In fact, no matter what the skill of the manipulator may be, it is almost an impossibility to remove from the cupel a bead representing 0.00001 per cent. of silver (when 10 grams is the quantity of rock taken for assay), even if the cupellation has been carried on very cleanly; and it is with such beads and even smaller that assayers who are searching for silver in country rocks have to deal. It is true that many of these rocks run as high as 0.001 per cent. (that is to say, 0.1 milligram, 10 grams being taken for assay) and some much higher; still, the beads from such rocks are often lost, and a great deal of inconvenience is caused thereby. The measuring apparatus which was used in the assays to be described can be adjusted to any microscope and it is very simple in construction. Many microscopes have a similar arrangement for centering and measuring crystals. It consists of two metallic plates, one above the other, to which a motion parallel to the vertical cross hair can be given as well as a motion across it. These two plates are fastened upon a third plate, which is attached to the shelf of the microscope. The accompanying diagram (natural size), Plate XXX, shows the arrangement and mode of movement of these two plates.

The letter *a* designates the plate on which the cupel is placed. This plate has a motion parallel to the vertical cross hair given to it by means of the screw *s* and the ratchet *r*, and it moves between the side plates, *b b*. This plate *a*, the side pieces *b b*, the screw *s*, and the ratchet *r* all rest upon a second plate, *ff*, which moves between the



ELEVATION.



PLAN.

THE MICROMETER MEASURING APPARATUS.

side pieces, *c c*, across the vertical cross hair. The motion from side to side is given to both the upper and lower plate by means of the micrometer screw *t*. This screw has 100 threads to the inch, and the micrometer *m* is divided into 100 parts, so that each division of the micrometer represents one-ten-thousandth part of an inch. It is preferable to use a micrometer divided into fractions of a millimeter, but when these experiments were made no such measuring apparatus was available. The screws *e e* hold the clamps *i i*, which are used to fasten the main plate of the micrometer to the shelf of the microscope stand. The following is the process of measuring: The cupel *k* is placed upon the plate *a* and by means of the ratchet screw *s* is moved until the silver bead occupies a position midway between the two horizontal cross hairs, which are represented on the diagram by the lines *h h* and *h′ h′*. The object of having two horizontal cross hairs is to enable the observer to bring the bead almost exactly into the focus of the objective. This is necessary, otherwise the measurements will be incorrect. It would be possible to center the beads by means of one horizontal cross hair, but then this cross hair would intersect the circumference of the bead just where it would be necessary to make the vertical cross hair tangent to it, and thus render the manipulation more difficult and uncertain.

Then, by means of the micrometer screw *t*, the two plates are moved parallel with the horizontal cross hairs until the circumference of the bead *o* becomes tangent to the vertical cross hair, which is represented on the diagram by the line *x y*. This operation is often attended with considerable difficulty, owing to the nature of the surface of the silver bead, which sometimes so reflects the light that it is not possible to clearly distinguish its edge. This can usually be remedied by changing the position of the reflector, but a better method is to expose the silver bead to a current of sulphureted hydrogen before attempting to measure it, which causes it to assume a dullish-brown color.

When the circumference of the bead is tangent to the edge of the cross hair, the mark on the micrometer opposite the stationary line *q* is noted (in the diagram it is at zero), and the screw is turned, care being taken to note the number of revolutions, until the vertical cross hair appears to be tangent to the opposite edge of the bead and occupies the position shown by the line *x′ y′*. Every time the zero mark is passed the distance is noted as a hundred, no matter what was the starting point, and then the figure marking the starting point is deducted from the number of hundreds (that is to say, revolutions of the screw), plus the number marking the end. Thus, if the screw, before it was started, stood at the 35 mark and was turned past the zero mark twice and was stopped at 25, the diameter of the bead would be 225−35=190=0.019 of an inch (0.482 millimeters). Of course it would be possible to set the micrometer at zero each time, but then it would be necessary to place the bead tangent to the cross hair by hand, which would be a tedious operation and one not attended with very exact results. In order to check this measurement, the screw must now be reversed and the bead again made tangent to $x\,y$. Frequently there is a difference between these two measurements of one or two marks of the micrometer, and either an average of these two can be taken or a new trial made and the four results averaged. It is, however, best, when great accuracy is required, to measure the bead until two successive measurements agree within at most one division of the micrometer.

An important constant in these measurements is the thickness of the cross hair. It will be noticed that the bead becomes tangent first to one edge of the cross hair then to the other. This is unavoidable, as it is almost impossible to place the outer edge (which in the first instance would be the left side of $x\,y$) tangent to the circumference of the bead, since the circumference would be covered by a portion of the cross hair. Considerable practice is needed to accustom the eye to the apparatus, but as far as accuracy of measurement is concerned it leaves little to be desired. A micrometer eye-piece on which a scale has been engraved can also be used for measuring beads, but it will not be found so convenient or so exact.

The calculation of the weight of silver beads from their diameters is a more difficult problem, and it has been necessary to make numerous experiments and measurements in order to determine what were the relations of the diameters of silver beads to their volume. It is thought, however, that the ratio which has been established by these experiments is correct, or at least sufficiently accurate for any of the requirements of the process. It must be borne in mind that this method is only intended for determining the weight of very small beads, such as it would be next to impossible to weigh on the most delicate balances.

MANIPULATIONS BEFORE MEASURING.

It is not necessary to give a detailed description of the various manipulations used in the silver assay, as they are so minutely explained in the standard works on assaying, but some account must be given of the methods of obtaining silver beads which in form are approximately near that of a sphere. At first an attempt was made to produce a bead of that character in an ordinary cupel, such as is used in the muffle, but after repeated experiments this means was abandoned.

It must be remembered that the quantities of silver present in the country rocks of mining districts are exceedingly small, rarely exceeding 0.001 per cent. (0.1 milligram when 10 grams are taken for assay), and that the present process has been elaborated in order to render the determination of these minute quantities a simpler and more expeditious affair. It may be said that small quantities of silver in such rocks can be determined by taking larger quantities, say 100 grams, or by making a number of assays and concentrating the amounts of silver in a single bead, which can be easily weighed and the actual value of the rock determined by dividing the weight of this bead by the number of times the standard assay weight (in these experiments, 10 grams) is contained in the total weight of the rock taken for assay. But this method is open to several objections. In the first place the obtaining of a weighable quantity of silver from rock that contains but 0.0001 per cent. is a long and tedious process, and it is just as important in tracing the source of the silver in mineral veins to determine the values of poor rocks as to determine the values of rich ones. Again, it is more than probable for several reasons that the concentration assay does not give as accurate results as a single assay carried out with great care. This is perhaps partly because there is a relative difference in the loss by cupellation between a small and a large quantity of lead. It may also be due in a measure to the difficulty of estimating the amount of silver obtained from the lead flux. The experiments in regard to this point have not yet been completed, although the results obtained so far indicate that there is usually a slight difference between the concentration assay and the single assay. Taking a large quantity of pulp, on the other hand, for assay has the advantage that it may give a better average of the rock. This is, however, insignificant, since, by pulverizing a large quantity of rock very fine and thoroughly mixing it, as good an average can be obtained from 10 grams as from 100.

If lead containing a very small quantity of silver, from 0.001 to 0.1 milligram in 10 grams, is cupelled in an ordinary cupel, the bead after it has brightened and cooled will be found to be either very irregular in form or if it is very small it will have been absorbed in the cupel altogether. This is owing to the coarse nature of the ordinary bone ash; in fact any bone ash, except the finest elutriated, will act in this way. An attempt was made to remedy this defect by using a cupel made in the following manner: The mixture for the cupel, which in this instance consisted of two parts bone ash and one part leached wood ash, was placed in the cupel mold and it was gently pressed into shape with the punch, which was then removed, and a layer of fine elutriated bone ash was spread over the top of the cupel within a radius of about 5 millimeters from the center. The punch was then driven home. This process produced a cupel which had excellent absorbing properties and at the same time offered a smooth surface for the bead when the moment of brightening arrived. It did not give satisfactory results, however, as it was found that the beads were still far from spherical, differences of as much as 0.05 millimeter occurring in beads the largest diameter of which did not exceed 0.3 millimeter. The irregularity was principally owing to the fact that the cupel had absorbed so much litharge that the bead could not brighten freely. Very minute quantities of silver did not disappear, however, as readily in the cupel.

The next attempt was more successful. The bead was cupelled in an ordinary cupel, which consisted of two parts of bone ash and one part leached wood ashes, and when it had been reduced to the size of a pea it was poured into a clean cupel, which had been prepared in the manner described in the preceding paragraph. The beads obtained in this manner were of fair form, the difference between their diameters rarely exceeding 0.015 millimeter; but still very minute quantities of silver would disappear in the cupel, leaving only a dark stain to mark their presence. The process of pouring from one cupel to another in the muffle was also an inconvenient one, and unless great care was taken a globule of lead would be found remaining in the discarded cupel. For ordinary purposes this method answers tolerably well, but it is not to be recommended when the greatest possible exactness is required.

In connection with cupellation it is well to describe here two manipulations which are of very considerable assistance. Most assayers have no doubt noticed that, no matter how carefully the lead regulus is freed from slag by hammering on the anvil, a certain amount of slag will always be found surrounding the silver bead after the cupellation is finished. This is of very little importance when the bead is a large one, but when it is a small one this slag materially interferes with the spherical form of the bead, thereby rendering its measurement unreliable. This collection of slag around the bead can be prevented in the following manner:

The cube of lead is cut into two pieces before it is placed in the cupel, and when it is introduced into the muffle care is taken to place the fresh, clean surface of the regulus upon the bottom of the cupel. In this way, when the lead melts, the slag will float on the molten metal and eventually form a ring around the edge of the cupel, leaving the silver bead entirely free.

Another convenience is the use of a glass tube to blow out or clean the cupels just before the lead is introduced. The tube should be about two feet long and slightly bent at the end which is introduced into the muffle. In this manner any dust can at once be removed from the cupels, thereby obviating the necessity of removing each one separately from the muffle.

Mr. Foehr, to whom reference has already been made, says that the final cupellation can be made before the blow-pipe. Although at the time (1878) when I was first obliged to make use of the Plattner scale to measure beads from the ordinary fire assay, no balance being available, I was not acquainted with Mr. Foehr's method, yet it occurred to me that it might be possible to obtain more perfect beads by means of the blow-pipe than by the muffle alone. Experiments were therefore made during the winter of 1884–'85 which proved highly satisfactory. The method adopted was the following:

The lead was cupelled in ordinary cupels in the muffle until it was reduced to a globule about the size of a pea. The cupel was then removed, the heat retained in it being sufficient to continue the operation for some little time, until upon cooling the lead bead was about the size of a No. 7 shot. This lead bead was then exposed to the blow-pipe for final cupellation, in the manner described in Plattner's Assaying.

It was found, however, that this operation was unnecessarily tedious. A mechanical blow-pipe was substituted and the method now to be described was adopted.

After the cupels had cooled the lead beads were removed from them by means of small pliers and carefully cleaned on a polished steel anvil. The cupels used were made of very fine elutriated bone ash and consisted of plain iron rings about 25 millimeters in diameter, with a height of 4 millimeters, in which the bone ash was stamped with the ordinary steel cupel punch. The rings were made by cutting off sections of gas-pipe of the required size and by turning the inside surfaces true in the lathe afterwards. A large number were made at one time, so that it would not be necessary to interrupt the process to make fresh cupels. The holder in which the cupels were placed was similar to the Plattner holder, except that the upper portion could be turned freely in a socket at the lower end of the handle. As the mechanical blow-pipe left both hands free the holder could be manipulated in this way with great convenience and accuracy. Fig. 50 represents the mechanical blow-pipe and

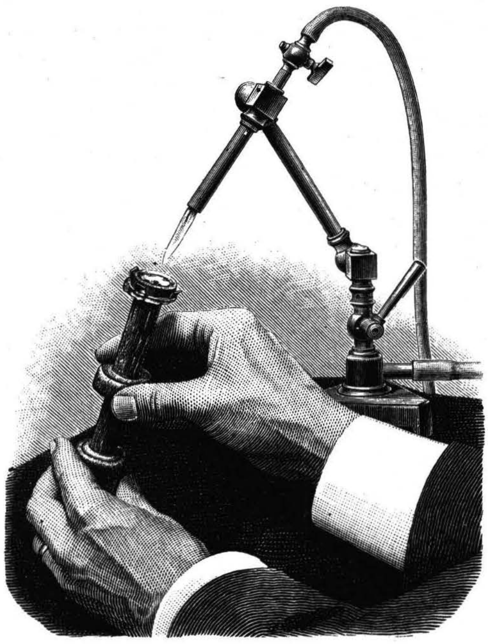


FIG. 50 —Cupelling apparatus.

the holder containing the cupel. This blow-pipe was composed of a simple gas jet, the blast being delivered through a tube in the center. The blast was furnished by a Richards filter pump, and the amounts of air and gas were regulated by separate stop-cocks. No difficulty was experienced in producing an even jet of flame of the proper intensity, which was controlled with ease. The lower portion of the cupel stand was held steadily in the left hand, while the right was used to turn the upper portion as the process of cupellation required. After the beads of lead had all been cupelled the silver beads were examined under the microscope, and if they were found not to be sufficiently round they were again melted before the blow-pipe, at the point of the flame. This mode of cupellation had great advantages, as it enabled the observer to clearly inspect the bead at the moment it brightened, a condition which is indispensable when the quantities of silver are so minute; and, not requiring such practiced skill as the method with the ordinary blow-pipe, the operation could be performed with less danger and smaller loss. This final cupellation must be conducted with great care, however, for any overheating of the alloy of lead and silver is attended with loss, as silver is very perceptibly volatile at high temperatures. A bead which has been overheated is surrounded by minute globules of silver which have been volatilized and deposited on the cupel, as can readily be seen under the microscope.

Although over three hundred assays were made in carrying out these experiments only those which were made by this last method will be referred to here. Many of the phenomena disclosed by the results of the assays cited were foreshadowed by the previous work, but as that work can only be regarded as preliminary and experimental it has not been relied on in making the deductions which follow.

At first in preparing silver beads for measurement an ore was selected which contained 1.0725 per cent. (311.80 ounces to the ton of 2,000 pounds). As this was too rich, it was diluted with a sufficient quantity of chalk to reduce its value to 0.1 per cent. (29.16 ounces to the ton of 2,000 pounds). It was found, however, that this would not answer, for, although the ore was passed through a screen with 100 meshes to the linear inch and was mixed with the chalk as thoroughly as possible, the mixture was not so homogeneous as the delicacy of the experiments required. Next an alloy of lead and silver was made which contained about the proper proportion of lead and silver. The value in silver was determined by repeated assays, the lead being carefully weighed. It was observed, nevertheless, that different pieces of this lead having the same weight differed perceptibly in their silver contents. Again, granulated lead was used, but it was found that it did not answer, as the three kinds which were experimented with contained metallic iron, a portion of which remained with the silver after it was cupelled, thereby rendering the bead very irregular in form. This would naturally be of little importance in ordinary assays, but when the quantity of silver was so small as in this case it materially interfered with the results.

Next very small chips were cut from ordinary rolled lead and thoroughly mixed together. A given quantity was accurately weighed and introduced into the hot cupel by means of a small scoop, care being taken to see that all the particles melted thoroughly together and did not remain adhering to the sides of the cupel. This method of preparing beads supposed to represent a certain value was found to be the best, though to some extent it is open to the same objection as the others.

The beads the measurements of which are given in the following table were prepared in this manner from sheet-lead which contained 0.00605 per cent. of silver (1.764543 ounces to the ton of 2,000 pounds or 0.605 milligram in 10 grams). The value of this lead was determined by the average of several assays of 50 grams each, the difference in weight between any two of the resulting beads not exceeding 0.05 milligram.

Record of assays.

Weight of lead, in grams.[1]	Number of the assay.[2]	Long diameter in divisions of the micrometer.[3]	Short diameter in divisions of the micrometer.[4]	Difference.[5]	Average difference.[6]	Extreme difference.[7]	Average of all the diameters.[8]	Average of all the diameters in millimeters.[9]	Calculated weight of the bead in milligrams.[10]	Estimated weight of the bead in milligrams.[11]	Ratio of estimated weight to calculated weight.[12]	Corrected ratio of estimated weight to calculated weight.[13]	Weight calculated by the formula, $x'=\frac{W}{D^3}\cdot d^3ar^{n-1}$.[14]
	1	165	163	2									
	2	163	163	0									
	3	159	157	2									
	4	163	158	5									
5	5	160	160	0	2.2	8	161	0.4089	0.3761	0.3025	0.8042	0.8038	0.302
	6	164	162	2									
	7	163	158	5									
	8	161	159	2									
	1	143	142	1									
	2	148	144	4									
	3	147	145	2									
	4	151	149	2									
4	5	149	147	2	2.	11	147	0.3733	0.2861	0.2420	0.8458	0.8361	0.235
	6	153	151	2									
	7	147	146	1									
	8	147	145	2									

[1] This column represents the weight of the lead taken to form the bead.

[2] The number of the assay in the set.

[3] The long diameter of the bead in divisions of the micrometer after deducting the width of the cross-hair. The micrometer screw has 100 threads to the inch and the head of the screw is divided into 100 parts, so that one division of the head of the screw represents 0.0001 of an inch. The width of the cross-hair is about 0.0002 of an inch (0.00508 millimeter).

[4] The short diameter of the bead in divisions of the micrometer.

[5] These are the differences between the two diameters of the same bead.

[6] This is the average difference of the diameters of the eight beads determined by dividing the sum of the differences by 8.

[7] The extreme difference is the difference between the smallest diameter of the smallest bead and the largest diameter of the largest bead.

[8] The average of all the diameters of all the beads is obtained by adding all the diameters of the beads together and dividing by 16, the total number of the diameters. It is expressed in divisions of the micrometer.

[9] This is the same average expressed in fractions of a millimeter.

[10] The weight of the bead calculated by the formula to be explained hereafter.

[11] The estimated weight is the weight which a bead should have which was derived from the amount of lead cupelled. This lead contained 0.605 milligram in 10 grams or 0.00605 per cent.

[12] The ratio of the estimated or supposed weight to the calculated weight is obtained by dividing the estimated weight by the calculated weight.

[13] The corrected ratio of the estimated weight to the calculated weight is obtained from the formula $l=ar^{n-1}$, which is explained hereafter.

[14] This is the weight of the beads calculated by the formula used in computing the tables.

Record of assays—Continued.

Weight of lead, in grams.	Number of the assay.	Long diameter in divisions of the micrometer.	Short diameter in divisions of the micrometer.	Difference.	Average difference.	Extreme difference.	Average of all the diameters.	Average of all the diameters in millimeters.	Calculated weight of the bead in milligrams.	Estimated weight of the bead in milligrams.	Ratio of estimated weight to calculated weight.	Corrected ratio of estimated weight to calculated weight.	Weight calculated by the formula, $x'=\frac{W}{D^3}.d^3xr^{n-1}$.
	1	136	132	4									
	2	134	132	2									
	3	137	132	5									
	4	132	132	0									
3	5	132	131	1	2.7	9	132	0.3352	0.2071	0.1815	0.8763	0.8699	0.173
	6	137	133	4									
	7	133	128	5									
	8	131	130	1									
	1	114	111	3									
	2	116	116	0									
	3	117	112	5									
	4	119	115	4									
2	5	116	112	4	2.4	8	114	0.2895	0.1334	0.1210	0.9070	0.9050	0.114
	6	116	116	0									
	7	117	115	2									
	8	114	112	2									
	1	93	92	1									
	2	92	92	0									
	3	92	87	5									
	4	94	90	4									
1	5	93	89	4	2.7	7	91	0.2311	0.0678	0.0605	0.8923	0.9416	0.069
	6	90	90	0									
	7	93	88	5									
	8	94	90	4									
	1	88	87	1									
	2	93	88	5									
	3	85	83	2									
	4	91	89	2									
0.9	5	89	88	1	1.7	10	88	0.2235	0.0614	0.0544	0.8859	0.9453	0.545
	6	90	90	0									
	7	90	88	2									
	8	89	87	2									
	1	85	83	0									
	2	84	82	2									
	3	83	82	1									
	4	85	83	2									
0.8	5	85	81	4	2.	4	83	0.2108	0.0515	0.0484	0.9398	0.9491	0.046
	6	85	83	2									
	7	84	82	2									
	8	85	82	3									
	1	83	81	2									
	2	82	78	4									
	3	82	82	0									
	4	78	78	0									
0.7	5	83	79	4	1.6	6	79	0.2006	0.0443	0.0423	0.9548	0.9528	0.039
	6	78	78	0									
	7	79	77	2									
	8	80	78	2									

Record of assays—Continued.

Weight of lead, in grams.	Number of the assay.	Long diameter in divisions of the micrometer.	Short diameter in divisions of the micrometer.	Difference.	Average difference.	Extreme difference.	Average of all the diameters.	Average of all the diameters in millimeters.	Calculated weight of the bead in milligrams.	Estimated weight of the bead in milligrams.	Ratio of estimated weight to calculated weight.	Corrected ratio of estimated weight to calculated weight.	Weight calculated by the formula, $x' = \frac{W}{D^3} d^3 a r^{o-1}$.
	1	76	73	3									
	2	76	76	0									
	3	75	75	0									
	4	77	75	2									
0.6	5	76	76	0	1.	4	75	0.1905	0.0380	0.0363	0.9552	0.9566	0.034
	6	77	75	2									
	7	76	75	1									
	8	76	76	0									
	1	72	70	2									
	2	71	69	2									
	3	73	73	0									
	4	72	71	1									
0.5	5	72	71	1	1.	4	71	0.1803	0.0322	0.0302	0.9378	0.9604	0.029
	6	73	72	1									
	7	71	71	0									
	8	73	72	1									
	1	69	67	2									
	2	69	67	2									
	3	70	67	3									
	4	68	65	3									
0.4	5	67	64	3	2.	6	67	0.1701	0.0270	0.0242	0.8962	0.9042	0.024
	6	67	66	1									
	7	69	67	2									
	8	70	70	0									
	1	63	61	2									
	2	65	61	4									
	3	62	59	3									
	4	61	61	0									
0.3	5	59	59	0	1.2	7	61	0.1549	0.0204	0.0181	0.8872	0.9681	0.018
	6	63	63	0									
	7	61	61	0									
	8	59	58	1									
	1	52	52	0									
	2	54	53	1									
	3	54	52	2									
	4	52	52	0									
0.2	5	52	52	0	1.1	4	52	0.1320	0.0126	0.0121	0.9603	0.9719	0.011
	6	53	50	3									
	7	53	51	2									
	8	52	51	1									
	1	40	39	1									
	2	42	40	2									
	3	42	42	0									
	4	43	43	0									
0.1	5	42	41	1	1.3	5	41	0.1041	0.0062	0.00605	0.9758	0.9758	0.005
	6	43	42	1									
	7	41	38	3									
	8	42	39	3									

METHOD OF CALCULATION.

It will be noticed that the diameters of the beads recorded in the third and fourth columns of the foregoing "record of assays" do not show a regular decrease exactly proportional to the amount of lead taken for cupellation. This is owing to several causes, in a slight degree to inaccuracies of measurement, but principally to small variations in the amount of silver contained in the lead and to the difficulty of obtaining beads of exactly the same shape. One bead may weigh the same as another, but may have larger or smaller diameters, according as it approaches an oblate or a spherical form. It must be remembered, however, that the differences which are brought so prominently in view in the table of records are but slight in reality, when the comparative delicacy of the measuring apparatus is taken into account. It is true that in extreme cases, an example of which is given in assay No. 4 of 5 grams, the difference in weight, calculated from the maximum and minimum diameters, amounts to 0.035 milligram. But the fact must not be lost sight of that neither one of these two diameters can be the true one, and, although their average is not always exactly what would have been the true diameter had the bead been spherical, yet this average is much nearer the true one than either of the extremes. Also, as the diameter decreases, the error of weight decreases more rapidly, although it forms a greater percentage of the actual weight. For instance, a difference in diameter of 5 divisions of the micrometer (0.012 millimeter) between 161 divisions and 156 divisions (corresponding to 0.302 milligram and 0.277 milligram, respectively) would give a difference in weight of 0.025 milligram, or less than 9 per cent. of the larger number; but a difference of 5 between 40 divisions and 45 divisions would give a difference in weight of 0.0022 milligram, or about 28 per cent. So it will be seen that the error in weight decreases with the diameter, although its ratio to the actual weight increases. In making these assays any bead was rejected which had a difference between its diameters of more than 5 divisions of the micrometer (0.012 millimeter).

It might be possible to calculate what shape a cooling bead of silver would assume and to determine what ratio the weight bore to the change in form; but before such a calculation could be made it would be necessary to determine the value of several constants, such as describe the effect of the capillary attraction of the bone ash of the cupel or of the litharge for melted silver, and the contraction of silver at the moment of cooling. A calculation based, therefore, entirely on the theoretical form of the bead would be attended with almost insurmountable obstacles.

The object of making the series of assays recorded in the foregoing tables was to establish, if possible, the ratio of the diameters of beads to their weight. For this purpose the average diameter of all the beads of a series was assumed to be the correct diameter for that series.

As a matter of fact the true diameter approaches the smaller rather than the larger diameter. The normal density of pure silver was taken as the density of the silver bead. The actual density of silver beads must be very close to that of pure silver, for it could not be materially changed by the small amount of lead retained by the silver or by the bone ash from the cupel which might adhere to the bead.

Let

10.505 be taken as the density of silver;

D = the diameter of a given globule of silver in millimeters;

W = its weight;

d = diameter of any other globule of silver in millimeters;

x = its weight;

Then

$$D^3 : d^3 = W : x$$

Now, if D = 1, then

$$x = \frac{Wd^3}{D^3} = \frac{W}{D^3} \cdot d^3 = 5.5005 \times d^3$$

In the foregoing table the calculated weights were obtained by this formula.

By dividing the estimated weight by the calculated weight a ratio is obtained which bears a certain relation to the shape of the bead. From the ratios given in the table it is evident that there is a definite relation between the diameter of the bead and these ratios, and although these ratios vary considerably among themselves they show in general a decided increase as the diameters decrease. Here again it might be possible to calculate a value for this ratio based on more exact and complicated mathematical principles than those which have been employed, but it must be remembered that the value of the ratio, as far as it affects the result, is so small that a simple method of arranging the differences or inequalities is preferable to one more complicated, especially as it is not intended to make this a mathematical paper. For the correction of these ratios a simple geometrical progression has been adopted, in which these ratios become the terms of the progression. The first term is represented by the fraction 0.9758 = a (the ratio of the 0.1 milligram series of assays) and the last term by 0.8042 = l (the ratio of the 5-gram series of assays), the number of terms = n being 50. In the first of these series of assays, where from 0.1 gram to 1 gram of lead were taken for assay, there would be 10 terms, but in the next of these series, from 1 gram to 5 grams, there would be 40, of which only the tenth term had been determined.

Let r = the ratio of the geometrical progression; then

$$r = \sqrt[n-1]{\frac{l}{a}} = \sqrt[n-1]{\frac{0.8042}{0.9758}} = 0.99605$$

The figures in the column "corrected ratio of estimated weight to calculated weight" were obtained by using this figure (0.99605) as the geometrical ratio of the progression in which the first term was 0.9758, the last term 0.8042, and the number of terms 50.

Richter says (page 37) that if the diameter of a sphere (globule) of silver was accurately determined and a scale calculated from that and the specific gravity of chemically pure silver, the weight of beads measured on it would need elaborate corrections and in the end would scarcely agree with the weights determined on a large scale (that is to say, taking larger quantities of the substance to be assayed). In other words, the specific gravity of chemically pure silver is not the specific gravity of the silver bead, and a calculation based upon the supposition that the beads are perfect spheres would not give the weight with any exactness.

As has already been stated, the slight difference that there may be between the density of chemically pure silver and that of silver beads can have scarcely a noticeable effect upon the calculation. Moreover, Plattner's scale itself has an important error connected with it, and that is that even very small beads of silver become more and more spherical as they diminish in size, as can easily be seen on a reference to the foregoing table; and the Plattner scale, therefore, being calibrated from a bead about a millimeter in diameter, gives too low weights from the fiftieth division down.

A close examination of the foregoing tables shows that the figures in the column "corrected ratio of estimated weight to calculated weight" correspond very nearly, especially in the assays from 5 grams to 2 grams, with those in the column "ratio of estimated weight to calculated weight" obtained from each set of assays. The ratios do not correspond in all the sets of assays, as, no matter how much care was taken in making beads which were intended to represent a certain value, inequalities in the amount of silver contained in the lead and irregularities due to slight inaccuracies in the process of cupellation would more or less affect the results. This was more particularly the case when small quantities of lead were taken to produce the bead. For this reason it was deemed best in calculating a formula for the computation of tables to put more reliance in the results obtained from large quantities of lead than in those obtained from small quantities.

The tables which accompany this paper were calculated by the following formula:

Let 10.505 be taken as the density of silver beads; then, as before (page 343),

$$x = \frac{W}{D^3} \cdot d^3 = 5.5005 \times d^3$$

But this result is too large by a quantity which increases as the size of the beads increases.

Let $0.804 = l$ be the ratio of the real weight to the calculated weight for a bead which has a diameter equal to 161 divisions of the micrometer (0.4089 millimeter), and $0.999 = a$ be the ratio of the real weight to the calculated weight of a bead the diameter of which is equal to 1 division of the micrometer (0.0025399 millimeter), such a bead being practically a sphere. Let n = the number of terms = 161, and r = the geometrical ratio; then

$$r = \sqrt[n-1]{\frac{l}{a}} = 0.99864$$

Let p=the ratio of the real weight to the calculated weight of any bead and x^1=the real weight; then

$$x^1 = \frac{W}{D^3} \cdot d^3 p$$

p, however, is equal to ar^{n-1} (where n represents the number of the division of the micrometer or the term which is to be determined); therefore,

$$x = \frac{W}{D^3} \cdot d^3ar^{n-1} = 5.5005 \times 0.999 \times 0.99861^{n-1} = 5.495 \times 0.99861^{n-1} \times d^3$$

THE DETERMINATION OF SMALL QUANTITIES OF SILVER IN COUNTRY ROCKS.

It has been stated before that the method just described is only applicable to the determination of the weights of very small beads. It is nevertheless possible to extend the usefulness of this mode of assaying to a very considerable extent. If, for example, it is desired to determine the amount of silver in a rock of considerable richness (say, 0.02 per cent. and upwards), it is only necessary to take such a fraction of 10 grams (the standard weight here adopted for assay) as would produce a silver bead of a size which would not exceed the limits within which the formula is calculated. Of course any error in measurement or in any other manipulation would be increased as many fold as the weight taken for assay was contained in 10 grams; but it must be remembered that the errors arising from incorrect measurement of beads increase in a ratio nearly proportional to the cubes of the diameters, and therefore a small difference in the measurement of a large bead would affect the results in a much greater degree than such a difference in a small one. For instance, an overmeasurement of 2 divisions of the micrometer (0.00508 millimeter) in a bead the true diameter of which was 50 divisions of the micrometer (0.127 millimeter) would give an error of 0.0013 milligram, but an overmeasurement of 2 divisions of the micrometer (0.00508 millimeter) in a bead the true diameter of which was 150 divisions of the micrometer (0.381 millimeter) would cause an error of 0.01 milligram or about 7.6 times as much.

The quantity of silver contained in the lead used as a flux in assaying poor country rocks, no matter in what combination the lead may be, has a very marked influence upon the results obtained. In the report on the Silver-Lead Deposits of Eureka, Nevada, attention was called to the importance of using a flux containing a minimum of silver. This becomes imperative when the silver beads are to be measured. Suppose it be required to determine the value of a rock containing 0.000059 per cent. of silver (0.017 ounce to the ton of 2,000 pounds).

If the flux used contained silver representing 0.00056 per cent. (0.16 ounce to the ton of 2,000 pounds), it would be impossible to put any reliance in the results, for several reasons. In the first place it would be impossible to determine within 0.000059 per cent. (0.017 ounce to the ton of 2,000 pounds) the amount of silver which would be reduced with the litharge and which would increase the size of the silver bead. This will be seen if reference is made to the third one of the following tables, which shows that the amount of silver reduced with the litharge is not a constant quantity, and, when the silver in the litharge is much in excess of that in the rock the value of which is to be determined, the results are very uncertain. Again, if there were 0.000059 per cent. of silver (0.017 ounce to the ton of 2,000 pounds) in the rock and 0.00056 per cent. of silver (0.16 ounce to the ton of 2,000 pounds) in the litharge, the bead resulting from the assay would weigh 0.0609 milligram and would represent 0.0000609 per cent. (0.177 ounce to the ton of 2,000 pounds). If an overmeasurement of 2 divisions of the micrometer (0.00508 millimeter) of such a bead is made, the resulting error amounts to 0.0039 milligram, or 0.000039 per cent., or over one-half as much as the amount of silver which is contained in the rock; whereas an error in measurement of 2 divisions of the micrometer (0.00508 millimeter) in a bead the diameter of which was equal to 41 divisions of the micrometer (0.104 millimeter), which would be the diameter of a bead representing 0.000059 per cent. (0.017 ounce to the ton of 2,000 pounds), would make only an error of 0.000008 per cent. (0.0023 ounce to the ton of 2,000 pounds).

In order to determine the amount of lead which different quantities of argol or of charcoal would reduce, numerous experiments were made, and it was invariably found that the greater the quantity of argol which was used with a given quantity of litharge the less would be the amount of lead which was reduced in proportion to the argol. This was also the case when argol was used as a reducing agent. The following tables explain themselves:

Reduction of litharge by argol.

No.	Weight of litharge.	Weight of argol.	Weight of reduced lead.	Ratio of reduced lead to argol.
	Grams.	*Grams.*	*Grams.*	
1	100	1	11.97	11.97 : 1
2	100	2	21.04	10.52 : 1
3	100	3	30.72	10.24 : 1
4	100	4	39.14	9.78 : 1
5	100	5	50.09	10.01 : 1
6	100	6	57.82	9.63 : 1
7	100	7	65.46	9.35 : 1
8	100	8	73.51	9.18 : 1

Reduction of litharge by charcoal.

No.	Weight of litharge.	Weight of charcoal.	Weight of reduced lead.	Ratio of reduced lead to charcoal.
	Grams.	*Grams.*	*Grams.*	
1	100	0.5	14.85	29.70 : 1
2	100	1	25.90	25.90 : 1
3	100	2	52.75	26.37 : 1
4	100	3	71.50	23.83 : 1
5	100	4	90.00	22.50 : 1

It will be noticed that in two cases, No. 5 in the first table and No. 3 in the second, there is not a decrease in the ratio, and also that the general decrease in these ratios is not a regular one. This is owing to the difficulty of making all the tests under exactly the same conditions. Although four different trials were made and every precaution was taken to render the results exact, such as finely pulverizing both the argol and the litharge and thoroughly mixing them, there was always some one of the series that made an exception to the rule. The experiments were made in crucibles of the same size in a gas furnace, and in each case the litharge was melted for the same length of time, with the same heat, and as nearly as possible under the same circumstances. The results, however, established the decrease of the ratio.

The amount of silver reduced from the litharge is not proportional to the amount of lead reduced, as can be seen from the following table. The larger part of the silver is reduced with the first lead, but this quantity increases somewhat with the amount of argol and the length of time during which the litharge is retained in a melted state. These facts are interesting to assayers, but they are only of practical value in showing the futility of using a flux which contains appreciable quantities of silver.

Reduction of silver and litharge by argol.

No.	Weight of litharge.	Weight of argol.	Weight of reduced lead.	Ratio of reduced lead to argol.	Per cent. of silver.	Ounces silver to the ton of 2,000 pounds.
	Grams.	*Grams.*	*Grams.*			
1	100	1	11.71	11.71 : 1	0.00054	0.159
2	100	2	22.41	11.20 : 1	0.00051	0.149
3	100	3	32.01	10.67 : 1	0.00056	0.164
4	100	4	42.46	10.61 : 1	0.00058	0.170
5	100	5	52.69	10.53 : 1	0.00065	0.192
6	100	6	63.61	10.60 : 1	0.00067	0.198
7	100	7	72.31	10.33 : 1	0.00072	0.210
8	100	8	81.00	10.12 : 1	0.00078	0.230

It has been mentioned that if metallic iron is present either in the country rock to be assayed or in the fluxes used a portion of this iron is retained by the silver bead. The iron seems to be alloyed with the silver in the bead, as those beads which were found to contain much iron had a different color and reflection from those which showed little or no reaction for iron. Usually, also, their form was more irregular. The presence of iron was detected by dissolving the bead in a drop of nitric acid in a watch glass, by evaporating slightly to drive off the excess of nitric acid, and by adding a drop of sulphocyanide of potassium. If iron was present a blood-red color appeared. It is only very small beads (less than 0.15 millimeter in diameter) which seem to be materially affected by the iron, though possibly all silver beads obtained in the ordinary process of assaying contain some iron. The presence of the iron is due to the use of iron mortars or other apparatus made of iron in crushing the rock or flux. The iron is necessarily in a very finely divided state, and during the process of melting the assay a small quantity of it is absorbed by the reduced litharge. While the bead is being cupelled much of this iron is carried off by the oxide of lead, but enough remains to seriously affect the results if the silver beads are very small. It is advisable, therefore, to use a hard flat rock, such as the Mexican miners crush their samples on, with a smaller one as a muller in grinding the substance to be assayed.

In general the following precautions will be found necessary in obtaining reliable results: The fluxes should be free from silver and metallic iron; the assay should be melted for a considerable time (not less than three-quarters of an hour when 10 grams are taken for assay) and at a high temperature; the cupellation should be finished before the blow-pipe in cupels made of the finest elutriated bone ash, care being taken not to have the heat too high; and, finally, the beads should be measured with the greatest possible accuracy. If the beads are not approximately round they should be discarded and other assays made; in fact, when it is important to determine small differences in the value of rocks with great accuracy, it is well to make duplicate assays.

TABLE OF ASSAYS.

The following table shows in milligram the weights of silver beads which have a diameter ranging from 1 to 161 divisions of the micrometer (0.00254 millimeter to 0.409 millimeter), 1 division of the micrometer being equal to 0.0001 of an inch; also, the percentage, the fractions of a troy ounce to the ton of 2,000 pounds, and the fractions of a dollar to the ton of 2,000 pounds which those beads represent when 10 grams of the substance are taken for assay:

Table showing weights of silver beads, number of troy ounces to the ton, &c., used in assays.

Divisions of the micrometer.	Millimeter.	Milligram.	Per cent.	Troy ounce to the ton of 2,000 pounds.	Dollar to the ton of 2,000 pounds.
1	0.002 54	0.000 000 090	0.000 000 000 90	0.000 000 263	0.000 000 34
2	.005 08	.000 000 719	.000 000 007 19	.000 002 10	.000 002 71
3	.007 62	.000 002 42	.000 000 024 2	.000 007 07	.000 009 14
4	.010 2	.000 005 74	.000 000 057 4	.000 016 7	.000 021 6
5	.012 7	.000 011 2	.000 000 112	.000 032 6	.000 042 2
6	.015 2	.000 019 3	.000 000 193	.000 056 3	.000 072 8
7	.017 8	.000 030 6	.000 000 306	.000 089 3	.000 116
8	.020 3	.000 045 7	.000 000 457	.000 133	.000 172
9	.022 9	.000 064 9	.000 000 649	.000 189	.000 245
10	.025 4	.000 088 9	.000 000 889	.000 259	.000 335
11	.027 9	.000 118	.000 001 18	.000 345	.000 446
12	.030 5	.000 153	.000 001 53	.000 447	.000 578
13	.033 0	.000 195	.000 001 95	.000 568	.000 734
14	.035 6	.000 243	.000 002 43	.000 708	.000 915
15	.038 1	.000 298	.000 002 98	.000 870	.001 12
16	.040 6	.000 361	.000 003 61	.001 05	.001 36
17	.043 2	.000 433	.000 004 33	.001 26	.001 63
18	.045 7	.000 513	.000 005 13	.001 50	.001 93
19	.048 3	.000 603	.000 006 03	.001 76	.002 27
20	.050 8	.000 702	.000 007 02	.002 05	.002 65
21	.053 3	.000 811	.000 008 11	.002 37	.003 06
22	.055 9	.000 932	.000 009 32	.002 72	.003 51
23	.058 4	.001 06	.000 010 6	.003 10	.004 01
24	.061 0	.001 21	.000 012 1	.003 52	.004 55
25	.063 5	.001 36	.000 013 6	.003 97	.005 13
26	.066 0	.001 53	.000 015 3	.004 46	.005 77
27	.068 6	.001 71	.000 017 1	.004 99	.006 45
28	.071 1	.001 91	.000 019 1	.005 56	.007 18
29	.073 7	.002 11	.000 021 1	.006 17	.007 97
30	.076 2	.002 34	.000 023 4	.006 82	.008 81
31	.078 7	.002 58	.000 025 8	.007 51	.009 71
32	.081 3	.002 83	.000 028 3	.008 25	.010 7
33	.083 8	.003 10	.000 031 0	.009 04	.011 7
34	.086 4	.003 38	.000 033 8	.009 87	.012 8
35	.088 9	.003 69	.000 036 9	.010 8	.013 9
36	.091 4	.004 01	.000 040 1	.011 7	.015 1
37	.094 0	.004 34	.000 043 4	.012 7	.016 4
38	.096 5	.004 70	.000 047 0	.013 7	.017 7
39	.099 1	.005 07	.000 050 7	.014 8	.019 1
40	.102	.005 46	.000 054 6	.015 9	.020 6
41	.104	.005 88	.000 058 8	.017 1	.022 2
42	.107	.006 31	.000 063 1	.018 4	.023 8
43	.109	.006 76	.000 067 6	.019 7	.025 5
44	.112	.007 23	.000 072 3	.021 1	.027 3
45	.114	.007 73	.000 077 3	.022 5	.029 1
46	.117	.008 24	.000 082 4	.030 3	.031 1
47	.119	.008 78	.000 087 8	.025 6	.033 1
48	.122	.009 34	.000 093 4	.027 2	.035 2
49	.124	.009 92	.000 099 2	.028 9	.037 4
50	.127	.010 5	.000 105	.030 7	.039 7

Table showing weights of silver beads, &c.—Continued.

Divisions of the micrometer.	Millimeter.	Milligram.	Per cent.	Troy ounce to the ton of 2,000 pounds.	Dollar to the ton of 2,000 pounds.
51	0.130	0.011 2	0.000 112	0.032 5	0.042 1
52	.132	.011 8	.000 118	.034 5	.044 5
53	.135	.012 5	.000 125	.036 4	.047 1
54	.137	.013 2	.000 132	.038 5	.049 7
55	.140	.013 9	.000 139	.040 6	.052 5
56	.142	.014 7	.000 147	.042 8	.055 3
57	.145	.015 5	.000 155	.045 1	.058 3
58	.147	.016 3	.000 163	.047 4	.061 3
59	.150	.017 1	.000 171	.049 8	.064 4
60	.152	.017 9	.000 179	.052 4	.067 7
61	.155	.018 8	.000 188	.054 9	.071 0
62	.157	.019 8	.000 198	.057 6	.074 5
63	.160	.020 7	.000 207	.060 4	.078 0
64	.163	.021 7	.000 217	.063 2	.081 7
65	.165	.022 7	.000 227	.066 1	.085 5
66	.168	.023 7	.000 237	.069 1	.089 4
67	.170	.024 8	.000 248	.072 2	.093 4
68	.173	.025 8	.000 258	.075 4	.097 5
69	.175	.027 0	.000 270	.078 7	.102
70	.178	.028 1	.000 281	.082 0	.106
71	.180	.029 3	.000 293	.085 5	.110
72	.183	.030 5	.000 305	.089 0	.115
73	.185	.031 8	.000 318	.092 6	.120
74	.188	.033 0	.000 330	.096.4	.125
75	.190	.034 4	.000 344	.100	.130
76	.193	.035 7	.000 357	.104	.135
77	.196	.037 1	.000 371	.108	.140
78	.198	.038 5	.000 385	.112	.145
79	.201	.039 9	.000 399	.116	.151
80	.203	.041 4	.000 414	.121	.156
81	.206	.042 9	.000 429	.125	.162
82	.208	.044 5	.000 445	.130	.168
83	.211	.046 1	.000 461	.134	.174
84	.213	.047 7	.000 477	.139	.180
85	.216	.049 3	.000 493	.144	.186
86	.218	.051 0	.000 510	.149	.192
87	.221	.052 8	.000 528	.154	.199
88	.224	.054 5	.000 545	.159	.206
89	.226	.056 3	.000 563	.164	.212
90	.229	.058 2	.000 582	.170	.219
91	.231	.060 0	.000 600	.175	.226
92	.234	.062 0	.000 620	.181	.234
93	.236	.063 9	.000 639	.186	.241
94	.239	.065 9	.000 659	.192	.249
95	.241	.067 9	.000 679	.198	.256
96	.244	.070 0	.000 700	.204	.264
97	.246	.072 1	.000 721	.210	.272
98	.249	.074 3	.000 743	.217	.280
99	.251	.076 5	.000 765	.223	.288
100	.254	.078 7	.000 787	.230	.297

Table showing weights of silver beads, &c.—Continued.

Divisions of the micrometer.	Millimeter.	Milligram.	Per cent.	Troy ounce to the ton of 2,000 pounds.	Dollar to the ton of 2,000 pounds.
101	0.257	0.081 0	0.000 810	0.236	0.305
102	.259	.083 3	.000 833	.243	.314
103	.262	.085 7	.000 857	.250	.323
104	.264	.088 0	.000 880	.257	.332
105	.267	.090 5	.000 905	.264	.341
106	.269	.093 0	.000 930	.271	.351
107	.272	.095 5	.000 955	.279	.360
108	.274	.098 1	.000 981	.286	.370
109	.277	.101	.001 01	.294	.380
110	.279	.103	.001 03	.301	.390
111	.282	.106	.001 06	.309	.400
112	.284	.109	.001 09	.317	.410
113	.287	.112	.001 12	.325	.421
114	.290	.114	.001 14	.334	.431
115	.292	.117	.001 17	.342	.442
116	.295	.120	.001 20	.351	.453
117	.297	.123	.001 23	.359	.464
118	.300	.126	.001 26	.368	.476
119	.302	.129	.001 29	.377	.487
120	.305	.132	.001 32	.386	.499
121	.307	.136	.001 36	.395	.511
122	.310	.139	.001 39	.405	.523
123	.312	.142	.001 42	.414	.535
124	.315	.145	.001 45	.424	.548
125	.317	.149	.001 49	.433	.560
126	.320	.152	.001 52	.443	.573
127	.323	.155	.001 55	.453	.586
128	.325	.159	.001 59	.463	.599
129	.328	.162	.001 62	.474	.612
130	.330	.166	.001 66	.484	.626
131	.333	.170	.001 70	.495	.640
132	.335	.173	.001 73	.505	.654
133	.338	.177	.001 77	.516	.668
134	.340	.181	.001 81	.527	.682
135	.343	.185	.001 85	.539	.696
136	.345	.189	.001 89	.550	.711
137	.348	.192	.001 92	.561	.726
138	.351	.196	.001 96	.573	.741
139	.353	.200	.002 00	.585	.756
140	.356	.205	.002 05	.597	.771
141	.358	.209	.002 09	.609	.787
142	.361	.213	.002 13	.621	.803
143	.363	.217	.002 17	.633	.819
144	.366	.221	.002 21	.646	.835
145	.368	.226	.002 26	.658	.851
146	.371	.230	.002 30	.671	.868
147	.373	.235	.002 35	.684	.884
148	.376	.239	.002 39	.697	.901
149	.378	.244	.002 44	.710	.919
150	.381	.248	.002 48	.724	.936

Table showing weights of silver beads, &c.—Continued.

Divisions of the micrometer.	Millimeter.	Milligram.	Per cent.	Troy ounce to the ton of 2,000 pounds.	Dollars to the ton of 2,000 pounds.
151	0.384	0.253	0.002 53	0.737	0.953
152	.386	.258	.002 58	.751	.971
153	.389	.262	.002 62	.765	.989
154	.391	.267	.002 67	.779	1.007
155	.394	.272	.002 72	.793	1.026
156	.396	.277	.002 77	.808	1.044
157	.399	.282	.002 82	.822	1.063
158	.401	.287	.002 87	.837	1.082
159	.404	.292	.002 92	.852	1.101
160	.406	.297	.002 97	.867	1.120
161	.409	.302	.003 02	.882	1.140

PRELIMINARY REPORT

ON

SEA-COAST SWAMPS

OF THE

EASTERN UNITED STATES.

BY

NATHANIEL SOUTHGATE SHALER.

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ILLUSTRATIONS.

SEA-COAST SWAMPS OF THE EASTERN UNITED STATES.

BY N. S. SHALER.

GENERAL INTRODUCTION.

Among the most interesting results of the interaction of the sea and land are the swamps formed along the ocean shore. Such swamp deposits are found along most coasts. Although the special considerations of this report concern only the swamps of the New England and the more northerly portions of the American coast, it will be desirable to consider the outlines of the history of all sea-shore swamps, at least to the extent necessary to make the way clear to our study of the more limited field.

A very little study of the sea shore will show the intelligent observer that detrital matter is there subject to very peculiar conditions which are not found away from the narrow field where the sea comes into contact with the land. Over the whole surface of the land gravity, made free to act by the work of rain and frost, constantly urges detrital matter down the slopes of the continents towards the sea shore. Over the surface of the sea floor, except within the narrow belt from a little above high water to a few score feet below that level, this detritus is either stationary or is affected by very slight impulses. Within this shore belt, where the wave action is great, the movements of detrital matter are extremely varied, according to the ever changing movements of the sea, which vary with each tide, with each storm, and with every alteration of the geographical outlines of the vicinity. By these movements of the water the sedimentary matter is carried in varied directions, sometimes from the land to the sea; again, by a slight change in the equation of the forces, from the sea floor to the land. Here a cliff is undermined and its waste torn to pieces by the waves; there a narrow wall beach is thrown across an estuary; or dunes, composed of sea sand cast back upon the land and heaped up by the winds, may march across the lea, converting fertile fields to desert wastes or clogging the course of the streams on their way to the ocean.

The general tendency of these sea-shore forces is to cut away those projecting parts of the coast which rise above its surface and to heap such part of the waste acquired thereby as may not be borne away from the shore line in the form of beach ridges, built along those parts of the shore which are so low as to present no cliff front to the waves. As the rivers in this part of the shore belt have the least fall, they are much hindered in their exit to the sea by these accumulations of débris.

Where there are great rivers bringing large quantities of sediment into the sea the swamp-building process is intensified, as in such positions the materials for the construction of beaches and the accumulation of morasses are more abundant; moreover, as is well known, the salt in the sea-water favors the precipitation of the mud, which is borne into it by the streams, and so the waves and currents have more waste at their command than in those parts of the coast where the silt comes from the beaches alone.

Whenever it happens that the shore line is undergoing a slow subsidence then the swamp-building conditions are made more favorable by the raised beaches which the sea is constantly building. This is conspicuously the case along the shores of the coast region from Chesapeake Bay to the Gulf, where the land is either subsiding or has been sinking in very recent times. These sea-built beaches, extending as long walls along the shore, hinder the outgoing of the land water, and thereby produce a vast extent of imperfectly drained country, which naturally has a swampy character. Even if a low shore is steadfast in its position in relation to the sea, the process of down-wearing of the land soon brings the surface into a condition of imperfect drainage. Any little elevation is lowered by erosion, and if the rocks be calcareous the leaching out of their soluble materials lowers them to near the sea level.

We should next notice the fact that the sea-board swamp deposits are divided into two distinct classes, viz, those which are formed with fresh water for their usual covering and those which are covered with salt or brackish water, to which the tides have free access. It is well known that there is a tolerably sharp demarkation between the organic life, both animal and vegetable, in the fresh water and that in the salt water. Moreover, the tidal action, as we shall see hereafter, brings a new element into the equation of forces involved in constructing the swamps to which it has access. The result is that the swamps covered by the land waters have the common type of terrestrial swamps, where the vegetable matter, with a chance admixture of river silt laid down during periods of flood, makes up the mass of the deposit; in the marine or salt-water swamps the salt-water grasses and sea-weeds commingle their waste with relatively large proportions of animal matter, and the ever-recurring tides supply a large share of detritus worn from the neighboring beaches. The result is deposits which have a large portion of inorganic silt in their composition.

The problem of swamp formation is further complicated by the fact that in southern countries, where the mean temperature remains high for a long period and where the dryness of the air at certain seasons is considerable, the fresh-water swamps are subjected to a much more active decay than those in more northern climes, where the season of great heat is short and the air is more generally moist. The result is that in southern regions the accumulation of swampy matter can never raise the fresh-water morasses much above the level of the sea, or at least above the level of permanent moisture. Moreover, as we go southward the mosses belonging to the genus sphagnum, which are the most effective swamp-building plants now living, disappear, and their place is not taken by other species. The consequence is that the northern swamps, due to the blockading action of the sea, have a much better chance of extensive growth than those of the south. On the Atlantic coast of North America the southern limit of free-growing fresh-water swamps is found at Cape Hatteras, the system of the Dismal Swamp being the most southern extensive morasses approximating to the northern type. South of that line the fresh-water swamps are more and more affected by the climatal conditions as we approach the tropics.

Although the conditions of recent or still continuing subsidence favor the development of morasses in the southern regions, they do not have the vigor of development belonging to similar structures in the more northern district. On the other hand, we have the fact that the northern sea shore is in a state of elevation, or at least its movements have in geologically recent times been generally in the direction of elevation, so that the effect of the sea in barricading the shore has been small. Moreover, the shore is usually bold in its nature, and the interior has decided slopes toward the sea-board.

On the whole, the production of inland swamps due to the barriers built by the sea has been much greater in the northern portion of the continent than in the southern districts, though, as we shall see, the swamps formed in this manner are by no means wanting in the regions south of Cape Hatteras.

The swamps resulting from the coast actions may be generally classified in the following manner:

Salt-water swamps—formed within the tidal influence by the combined action of salt-water plants, animals of various groups of invertebrates, together with detrital matter brought in by the tides;

Fresh-water swamps—formed when the lowlands have their drainage hindered by the barriers made by the rivers, composed of fresh-water plants, together with alluvial matter brought in by the fresh-water streams;

Estuarine swamps—formed where essentially fresh water is lifted and lowered by the tide, composed in the main of grasses and the alluvium of rivers. This group is very limited in its range. It may be illustrated by the case of the "vleys" or swampy borders of the Hudson River.

THE COAST SWAMPS OF NEW ENGLAND.

The development of the shore swamps of New England is intimately connected with the glacial history of this district during the last ice period. The forces at work in that period determined the shape of the surface and thus fixed the outline of the shore. The oscillations of level attending on the coming and going of the ice sheet did much to determine the history of the coast line. It will therefore be necessary to preface the account of the New England coast swamps with a brief statement concerning the effects of glacial action on its territory.

The rocks which underlie the surface over New England are of exceedingly diverse hardness: long-continued mountain-building actions, together with extensive local metamorphism, the intrusion of dikes, vein structure, &c., have brought these rocks to a state when the same degree of resistance to eroding agents is never found over any extended area.

The result of this irregular resistance to erosion was to give the surface, when being acted on by ice, an exceeding diversity of outline There are very few parts of this region between the Hudson-Champlain Valley and the Atlantic which have the bed rock horizontal over any area of even an acre of extent. I have rarely found a surface of this area with average inclination of less than five degrees of slope. The principal feature of the topography is the occurrence of long, deep troughs, with undulating floors, the axes of which lie in the direction of the old mountain synclinals.

It is a marked feature of this district (probably, indeed, of all regions which have their erosion outlines determined by glacial action) that the troughs or synclinals of the mountain folds are more eroded than the anticlinals. Observations on regions south of the glacial belt show that there the reverse is the case, the anticlinals receiving the most wearing and the synclinals the least; so that the latter axes become in time the highest parts of the country. As these anticlinals and synclinals of New England have in general northeast and southwest trends, or rather trends which run a little to the east and west of the meridian, the outline of the shore is in a great measure determined by their courses. As none of these troughs is smooth, but all are extremely irregular, owing to the erosion done by the ice, the contact of the sea with the shore has the peculiar aspect known as the fjord structure. This is not a peculiarity belonging alone to the shore line of glaciated countries, but is the shape which that line necessarily assumes where the level of the sea is laid against the land. If the New England coast were to be lowered by several hundred feet, as it was lowered at the close of the last glacial period, the shore line would be found to have the same fjord structure as at present.

An examination of the detailed maps of the United States Coast Survey giving the topography of the coast between New York and Eastern

Maine will show the reader that this fjord topography is expressed along the whole of this coast line. It is most distinctly shown in the section from Eastport to Portland, where the trend of the shore is such that the coast line cuts across the axes of the synclinals; it is less distinct in the section from Portland to Cape Cod, where the coast follows more nearly parallel to the direction of the mountain troughs, but it again becomes very clear in the section from Cape Cod to New York, where the trend of the coast is more nearly at right angles to the axes of the synclinals than on any other part of the coast south of Nova Scotia.

A glaciated district affords peculiarly favorable conditions for the development of both salt-water and fresh-water swamps. On the land the glacially formed contours afford abundant basins, which at the outset are lakes, but in time become converted into morasses. The formation of shore swamps is favored by the existence of abundant recesses or embayed portions of the shore, in which such accumulations can be protected from the assaults of the greater waves. The process of development of these salt-water marshes may be studied in almost any of the fjords of this shore. Their history is in general as follows, viz: At the close of the glacial period there was a time in which the coast was subjected to several sudden alterations of level. The rapidity of these movements is indicated by the general absence of old beach-marks within the belt occupied by the sea during the changes of level as well as by the condition of the kames and kindred glacial structures which have passed through the shore line in the process of rising and sinking of the land. Finally the land recovered from the extreme unsteadiness which the glacial conditions caused and assumed its present generally steadfast position. The rapid changes of level ceased at a time probably not more than ten thousand years ago, since which time the conditions now at work have been in operation.

The action of the waves on the shore is the first point that requires our attention. This action is greatest on the exposed headlands of the coast, for there alone do the waves have their greatest height. The materials composing these headlands are worn away and beaten into fragments, which are carried in the direction in which the waves are moving. The fragments formed by the beating of the waves are carried to the nearest beaches, which are always more or less inland, in reference to the eroding cliffs. On these beaches the pebbles are slowly ground into fine mud, which may be easily carried even by slight currents for considerable distances. A considerable part of this mud is taken out to sea by the undertow or bottom current which always sets from a storm-beaten beach along the bottom, but another part is urged by the movement of the water caused by the waves and of the tidal flow into the fjord, where it falls to the bottom. In this process of carriage the mud is generally conveyed along the shores and is most commonly deposited in the parts of the inlets near the shore line. Wherever there is a bay within which the tidal current is deadened and where the waves have little play, this sediment is most rapidly laid down. If the process of deposition begins on a pebbly bottom, it is at first aided by the irregularities between the stones and the friction of the water among the sea-weeds, which frequently attach themselves to the stones. As soon as a sheet of mud is established, it commonly becomes occupied by a dense growth of eel-grass. This plant by its habit of growth greatly favors the deposition of sediment. The separate stems are set very close together, the interspaces not generally exceeding one or two inches. A tidal current of two miles an hour, swift enough to carry much sediment, is almost entirely deadened in this tangle of plants.

At half tide on the New England coast these eel-grass fields are generally covered with water to the depth of several feet; at this stage the tidal currents are commonly strongest. The water above the level of the grass has its usual freedom of motion and brings much sedimentary matter above the level of the foliage. As the tide falls a part of this waste is entangled and held until it gradually sinks to the bottom, so that each run of the tide gives a certain contribution of sedimentary matter, which goes to shallow the water. This process is easily observed from a boat floating over a field of these plants. The deadening of the current when the lowered tide brings the tops of the plants near the surface is very noticeable. The mass of floating matter—mud, fronds of sea-weed (often with shells or small pebbles attached to their bases), dead fish, and a mass of other refuse—is seen to collect in the mesh of foliage and sink to the bottom. The dead stems of the eel-grass and the bodies of many small crustaceans and mollusca which live on its stalks or on the bottom contribute to the deposit, so that it thickens with considerable rapidity.

When the bed formed on the sea bottom by the action of the eel-grass and its associated plants has risen to the point where it is dry at low water of the ordinary run of tides, the eel-grass can no longer maintain itself, but gives place to other groups of sea weeds and grasses.

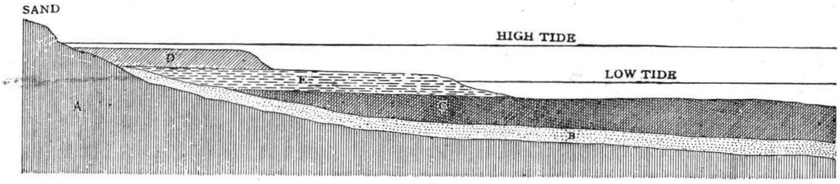


FIG. 51.—Diagrammatic section through a growing marine marsh.
A, bed rock. B, sand and gravel. C, eel-grass. D, upper marsh. E, mud-flat.

These species of plants find their place first near the shore line, where the eel-grass platform is naturally the highest. At first their vegetation is quite sparse, owing to the difficulty with which they endure the depth of water at high tide. There is often, indeed, a considerable difficulty in establishing the growth of the second group of plants, and for a while the deposit takes the shape of bare mud-flats, dependent in the main for their accumulation of detrital matter on the growth of certain mollusca, especially of the genera mytilus and modiola. It often happens that the scouring action of the tide restrains the upward growth for a long time; this is indicated by the very wide bench that lies between the level where the work of the eel-grass ceases and the higher plants establish themselves. Although this bench in most cases only extends through a vertical height of from three to four feet, the height depending on the measure of the tidal rise, it is often a mile or more wide. It constitutes the mud-flats of our shores.

When, as is usually the case, the more highly organized plants have difficulty in establishing themselves over the broad surface of the mud-flat, they win their way to it in the following manner, viz:

From the vantage ground of the shore line, where these plants easily find the conditions of submergence which suit their needs, the plants slowly extend the front of their bench out over the mud-flats (see Fig. 51).

This process of growth can be more easily studied than that of the earlier or eel-grass stage of the marshes, for it is visible along miles of our shore. The higher grasses have even more thick-set stems than those of the eel-grass flats; they entangle sediment even more effectively. At first their stems are covered for a few hours at each ordinary tide; they gather waste rapidly, and soon lift the plain which they are constructing up to the point where only at the highest tides are the tops covered by the water. At this stage the growth of the deposit is practically arrested, there being no means of increase save from the decay of the grasses themselves. At this period of growth the entrance of much sediment upon the area is strongly resisted by the tall grass upon the periphery of the marsh. The sediment is arrested upon this outer fringe of the plain, which is thus enabled to gain with considerable rapidity upon the mud-flat by the horizontal extension of the terrace, while, at the same time, it is constantly growing in height until it attains the maximum elevation of the deposit. This outer edge of the upper terraces of the morass is subjected to the constant friction of the tidal currents, as well as to the beating of the waves and the grinding of the ice in the winter season, so that in most cases its gain upon the area of the mud flat is slow.

The principal resistance to its extension comes from the action of the waves; by their blows a considerable amount of the face is worn away and the waste is distributed over the mud flat, thus adding to the thickness of that deposit and preparing it for the occupancy of the higher plants. In winter the ice chafes against this face with the rising and falling of the tide, often proving destructive to it. It is often seen to be undermined by these eroding agents; but in this case the superficial mat of closely interlaced roots holds together, and falling down over the escarpment acts as a revetment or curtain, securing it from further wear and preparing the way for its speedy restoration by the rapid growth of the grasses in their new position. It is only when the waves have a sweep of a mile or more that they can effectively arrest the extension of the sheet; even then it is necessary that the tidal current be strong enough to bear the débris away from the mud flat before the victory of the waves is in any way lasting.

There is, however, a more definite limit to the encroachment of these upper-level salt marshes upon the tidal streams. As the marshes extend they narrow the channels occupied by the free-running tide until they reduce its flowage-ways to very limited bounds, the lines of which are determined by a delicate adjustment of the forces which extend the marsh area and the destructive scouring action of the tide exercised on its growing edge. There is no other case in nature, save in the coral reefs, where the adjustment of organic relations to physical conditions is seen in such a beautiful way as in the balance between the growing marshes and the tidal streams by which they are at once nourished and worn away.

The system of tidal circulation in a salt marsh is fairly well shown in small maps of the Green Harbor and Plum Island marshes, in which the main channels of this circulation alone are delineated. Besides these larger inlets of the tide there are many smaller channels which ramify through the marsh, by which the waters find their way over its surface, thus escaping, in a measure, the resistance which the close-set grasses would make to its direct passage over the swamp. So branched are these channels that there is hardly an acre of the natural swamp which is without one of their water-ways; its steep sides and tortuous course show its constant battle with the encroaching plants, which naturally grow with the most vigor near its banks. Owing to the fact that the greater part of our salt marshes have been partly subjected to the care of man, these narrow channels are often obliterated. The hay which the salt marshes produce, though scanty in quantity, has a certain value and is much esteemed by the New England farmers. These natural channels were much in the way of the harvesting of the hay crop, so nearly all these swamps have been ditched in such a way that the water now finds its entrance and egress by a system of artificial parallel channels a few rods apart. By this means the hay wagons and the mowers can find well arranged ways for their operations and the marsh is more quickly drained. Owing to these artificial channels, the natural streamlets have often disappeared, their beds rapidly growing up when the currents through them were directed into the artificial ways.

Even where this artificial modification of the swamps has changed the regimen of their lesser creeks, this water system remains one of the most beautiful exhibitions of natural forces which the sea shore affords. There being everywhere the same pressure of the growing sod against their streams, they are free to cast their curves into exactly the form which the pendulum motion of their currents demands. At first sight it seems to the observer that the creek or salt-water stream is under much the same conditions as a fresh-water river traversing an alluvial plain; but a little observation will show him that the circumstances, though in a manner related, are in most ways extremely different. In the case of a true river its flow is constantly in one direction, and though the volume and energy of its current vary from time to time, it is only irregularly and at long intervals. In the salt-marsh river the flow is alternately in either direction, up or down stream, and this in a rhythmic manner twice each day, with brief intervals of perfect repose. The result is that the symmetry of the tidal-river curves far exceeds those of any fresh-water stream. In the river the effects of the frequently varied conditions can be traced in the curves, however symmetrical they may be; this gives them a certain irregularity. In the tidal river they may be perfectly balanced in their curvatures. In the fresh-water river the stream in the section where it is bordered by alluvial plains is usually burdened with a vast body of sediment, with which it is constantly struggling. It also brings a great deal of driftwood, which, lodging on the bottom or on the banks, perturbs the natural oscillations of the current and makes the outlines of the channel irregular. In the tidal river there is never any large amount of sediment; in no case enough to form bars; there is no driftwood; twice each day the perfect stillness of the water permits its burden to fall to the bottom. The only likeness in symmetry to these tidal rivers is found in the fresh-water swamps, whose clear natural streams flow through matter resembling in its process of growth the peat of the salt-water swamp, but even there the changes in the volume of the current make its curves less beautiful than those of the tidal marshes.

Although the foregoing account of the general history of the salt-water swamps of the Atlantic coast is true of these structures as a class there are certain differences in their character which depend upon circumstances peculiar to the various districts where they are formed. In regions where the soil is sandy, as, for instance, along the southern coast of Long Island, New York, the process of filling the shallows to the point where the grasses of the higher level may seize upon them is rapidly accomplished by the currents bringing in sand from the easily-worn headlands, so that the earlier or eel-grass stage of construction is omitted. In such regions extensive salt marshes may lie directly on a deposit of sand. Where the amount of drifting sand is very large it may entirely fill up the areas suitable for salt marshes before they have time to form.

The extent of the mud-flat stage of the developing terrace is also determined by the intensity of the tidal action, which in turn depends mainly on the height to which the tide rises. Where in the region near New York the tidal rise does not exceed about eight feet the currents are weak and their carrying power is relatively small. In the district bordering on Long Island Sound the shore is not exposed to the open sea and the wave action is slight. These causes combine to make the sediment brought upon the flats of that region small in quantity and of very fine grain. The mud-flats are but little scoured and the tidal friction against the escarpment of the upper level of the marshes is slight. In this region the mud-flats, though often made, are not so deep nor so extensive in area as they are along the more northern shores.

Along the New England shore from Cape Cod to Portland, Me., the increased height of the tide and the greater freedom of movement of the sediment caused thereby, together with the greater action of the ocean waves on the unprotected shore, increase the rate of growth in the eel-grass level and add to the depth of the section occupied by the mud-flats.

Going as far east as the Bay of Fundy, where the tidal currents have several times the carrying energy which they have about New York and where the rocks exposed to the assault of the waves are of a softer nature than any other except the clays and sands of Tertiary or post-Tertiary age, we find a sudden increase in the proportion of sediment carried by the tidal currents. The greater part of this sediment is contributed by the Paleozoic and Mesozoic rocks of this section, principally by the red sandstones and shales of the Triassic period, which are exposed to the erosive action of the sea along extensive marine escarpments. The geological origin of this sediment is indicated by its prevailing red color, that being the hue of the greater part of the Triassic rocks of this district.

The quantity of this mud is very great; the currents which sweep it about are of remarkable strength, it being not uncommon to find tidal streams flowing with a current of six or eight miles an hour in the middle half of the tidal movement. The result is that wherever there is a deep bay in the recesses of which the tidal motion is slackened we find a very extensive deposit of mud. In this region, such is the energy of the currents and the amount of the sediment that both the eel-grass and the upper-grass portions of the detrital terrace are relatively limited, and the mud-flat portion is the striking feature in the coast topography. On the central parts of the New England shore, as about Boston, the mud-flat occupies at most two or three feet in the altitude above mean low tide and the annual addition to its mass in a year is very small. Thus in this latter district so slight are the currents which flow over the upper level of the marsh that the mud material which they deposit may not amount to as much as one-tenth of an inch a year. On the other hand, in the Basin of Minas, one of the principal inlets leading from the Bay of Fundy, the contribution of sediment is so great that vast areas have been easily reclaimed from the sea by building a rude inclosure around an area of the higher parts of the mud-flat, so that the speed of the sediment-laden waters is checked and they are made to lay down their burden. In a few years, often in a few months, this inclosed area is raised to near the level of high tides. It is then only necessary to erect a barrier sufficient to exclude the tide, with exit gates for the rain-water, in order to have the land completely reclaimed from the sea. In this simple way there has been an area of many thousand acres of excellent arable land created along these shores.

The area occupied by the swamp deposits in different sections of the shore depends upon a variety of conditions. One of these, the presence of sheltered bays, has already been noticed. The original depth of water in the inlets is also a matter of great importance. These marshes are relatively rare along the coast of Maine, because the fjords of this section were originally very deep and the headlands are of such enduring rock that there is little waste formed by the waves which can go to shallow their bottoms to the point where the construction of the swamps can be begun. It will be some thousands of years before this portion of the shore has its waters shallowed to the depth where the marine swamps can begin to effect extensive reclamations from the sea. Although there are no very extensive salt-water swamps in the section between Portland and Eastport, they are frequently present as fringes along the shore, where the position is sheltered from the waves and the water is not too deep and the tides bring their usual supply of sediment. Along the Massachusetts shore the fjords were not originally as deep as those on the coast of Maine, and the very large amount of glacial drift on this part of the coast afforded material for the shallowing of the floors of the inlets to the point where the sea-weeds could begin their work of catching the sediment.

The presence of large amounts of pebbly material along a shore is also favorable to the formation of salt marshes by giving the waves an opportunity to construct barriers behind which the marshes may develop. These barrier beaches are particularly abundant along the Massachusetts shore, where the sea has abundant access to glacial pebbles and the coast is sufficiently open to the action of the waves to enable them to do their full measure of work. The best example of this action is seen in the Ispwich marshes, just south of the Merrimac River, and in the marshes about the mouth of the Saugus River, near Boston. The method in which these new inclosures are formed by the construction of barrier beaches is as follows:

When the coast shelf has been shallowed by the accumulation of sediment to the point where the space between the capes of a bay has been brought to within about 20 feet of the surface at the time of low tide, the conditions are favorable for the closure of the inlet by a barrier beach. In some time of heavy tempest, when the waves are running with energy into its open mouth, the seas mount too high to pass over the shallow without breaking. This breaking of the waves is caused by the excessive friction of the bottom of the wave on the floor of the sea, which so retards its on-going that the upper part of the wave shoots over the lower part and tumbles into confusion. It is precisely the process so easily observed when the waves break on a shelving beach. As soon as the process of breaking begins, the forward motion of the wave is arrested, and the detritus which it was urging forward at once falls upon the bottom immediately in front of the arrested waves. In this way the barrier beach is begun. (Fig. 52.)

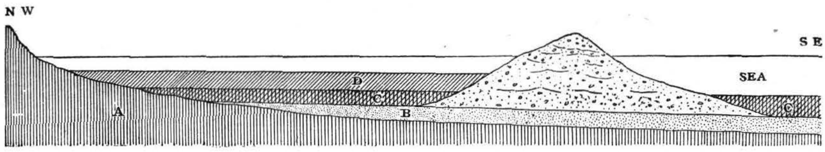


FIG. 52.—Diagrammatic section through Chelsea Beach and Saugus Marsh. A, Bed-rock. B, Sand and gravel. C, Eel-grass layer. D, Upper marsh.

At first the beach may consist of a reef which does not rise above the water level, and probably is not complete across the whole of the space between the headlands of the bay; but generally the incoming mass of detritus carries the submerged ridge of the beach up to the level of high water, and the sea-wall is formed. Several excellent types of such barriers may be found on the northern shores of Massachusetts Bay in the beaches of Chelsea (or Revere), Lynn, and of Marblehead. If the beach stretches across the whole of the exit of the bay, there is an accumulation of land water behind the barrier which soon forces an exit. This exit may be permanent, as is the case with the exit from the marshes behind Chelsea Beach, and in most other cases where the inclosed area is large, or it may be subject to frequent closure, as is the case with the beaches on the south side of Martha's Vineyard, Cape Cod, and elsewhere, where the waves and tidal currents have a large amount of sand under their control. In these cases the outlet is constantly opening and closing.

If a tolerably constant connection with the sea be maintained, then the salt marshes, beginning with the eel-grass stage, rapidly win the ground from the sea. The front of the beach becomes a vast mill, upon which sediment is ground into the state of mud, to be swept into the area of the bay with the ingoing tide. The conditions given by such a barrier beach are the most favorable for the formation of salt marshes, as they include a large area of shallow water and an extensive sea beach, where a great amount of sediment, both organic and inorganic, may be produced. We consequently find that such areas are commonly completely occupied by salt marshes, except where lie the streams necessary for their natural irrigation.

If, however, the barrier between the lagoon and the sea is at times closed, so that the water in the lagoon becomes fresh, the result is that the plants which are especially adapted to the production of salt marshes are killed by the fresh waters, while the occasional invasion of the salt water destroys the fresh-water plants, which might otherwise establish a swamp of their species. By these alternations some of the largest bays on the sandy shores have been kept from the invasion of the swamps, which would probably have been closed by them if the bays remained either fresh or salt water areas for a few thousand years. These inlets, where the growth of the salt marshes is liable to frequent interruption, are most common along the sandy shores of the coast, for the reason that in these regions the storms are able to shift large amounts of detritus in a short time, easily blocking the inlets to the lagoons, making the change to fresh water until some period of flood, when the land waters again establish a breach large enough to permit the tide to resume its work.

Although the regions where sand is abundant are, on the whole, unsuited to the normal growth of swamps, they are peculiarly favorable to the development of lagoons, which, except for the frequent alternations in the character of their water, are very well adapted to the growth of the swamp-making plants of the sea. An inspection of the Coast Survey charts will show the reader good specimens of these lagoons along the whole shore which is bordered by sandy material from Portland to New York. The commonest type of the lagoon is that which is formed by the breaking of the waves across the mouth of a bay, as before described. As these beaches are composed in the main of sand, they give little waste for the filling of the bay, for sand, as is well known, wears very little under the beating action of the waves. Another form of lagoon is produced by the extension of what are commonly called "hooks," which are in effect beaches that are extended beyond the shores on which they begin to form. When the projecting reef of the beach encounters a cross-current it is often so turned that it extends at an angle to its line of original growth, forming a great elbow, which embays an extensive area of water. Sometimes another beach forms across the open side of the bay thus created, completing the inclosure of the lagoon. The best specimen of this structure which our coast affords is that at the east end of Martha's Vineyard, known as Cape Poge (Fig. 53).

This promontory has the peculiar double beach, affording a complete inclosure within the sea built walls. Ordinary sand "hooks" of various sizes abound along the shores of Cape Cod and the region to the westward. Indeed, the eastern extremity of Cape Cod itself, including the northward-trending portion of its arm, is probably in large part of this nature. Except in cases where these inclosures are too much open to the sea, permitting the entrance of waves which are so strong that they break up the swamps, these lagoons are all the seats of such deposits.

There are certain general considerations connected with these salt-water swamps which deserve attention. First, we may note the fact that, although the New England shore affords unmistakable evidence of frequent alternations of elevation and subsidence within very recent times, no evidence of elevated marshes has ever been found. Although the upper coating of vegetable matter would doubtless soon decay and in a short time lose all distinct likeness of its original shape, its character as a shelf abounding in organic remains and having a horizontal form should remain, provided these terraces were ever built at higher levels which are now above the plane of the sea. At many points along the shore, especially on the coast of Maine, and in other parts of New England, there are abundant deposits of clays known as Leda clay, which have been well preserved. These deposits were formed in deeper water than is required for the accumulation of salt marshes, and are hardly more likely to be preserved.

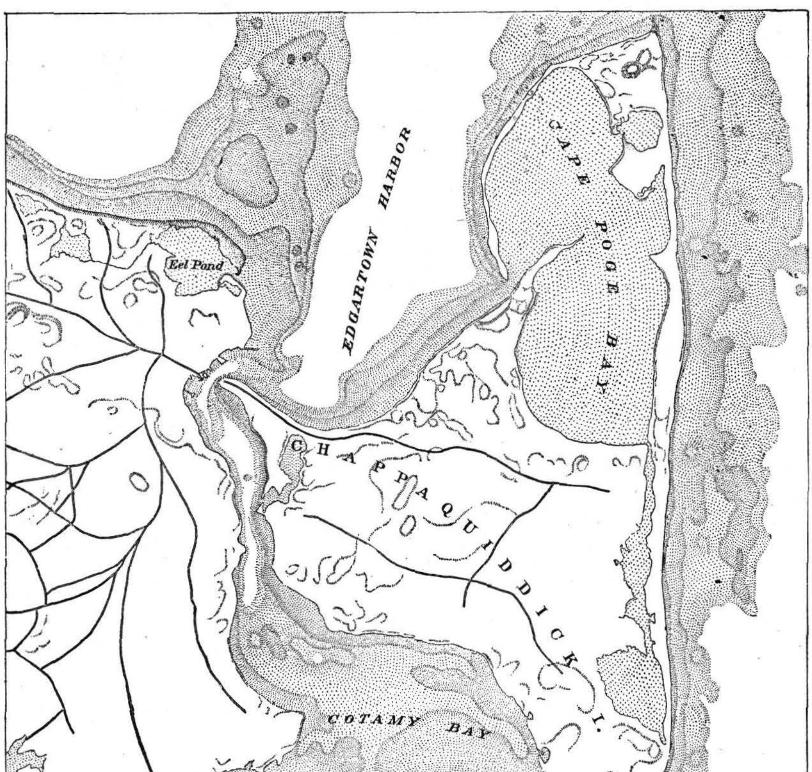


FIG. 53.—Hooks at eastern end of Martha's Vineyard.

This general absence of terraces which we might assume to have been marine marshes formed on the shores above the level of the sea at the close of the glacial period affords a fair presumption that these morasses have only begun to develop in an important way since the shore assumed its present level. This may be explained by the fact, abundantly shown by the absence of ancient erosive beaches and other evidence, such as that from the kames, &c., that the duration of the subsidence at the close of the glacial period was very brief, and that the sea very quickly attained its present altitude, pausing at no time long enough to develop the characteristic features of a shore line.

Although there are no signs of old marine marshes above the present tide line, there is reason to believe that there are at some points considerable areas of salt marsh formation below the present level of the sea. On many of the New England beaches it is not uncommon to find large masses of the characteristic matted roots of the upper-level marsh-plants which have evidently been long buried beneath the sea. These fragments are particularly common along the north shore of Massachusetts Bay, though they are found at times along the whole coast from Portland to Long Island. Although it is possible that the detritus may represent masses of the present shore swamps, which have been carried away to deeper water by the action of ice and other transporting agents, and subsequently rejected by the sea, it appears to me most reasonable to look upon them as fragments of swamp deposits which have been buried by subsidence. This view is supported by many other facts, such as the occurrence of submerged forests, which go to prove recent subsidence of the coast line between Portland and New York.

Before passing from the general consideration of these salt marshes to take up the economic problems which they suggest, it will be worth the reader's while to consider certain general features of these singular structures. The remote and picturesque coral reefs have long proved fascinating subjects to the geological student, while these near-at-home structures, which are in their way almost as interesting as the work of the polyps, have never been adequately studied. In the northern part of Europe they have been the subject of much economic consideration, but there seems to be no scientific literature whatever on the subject. Yet these swamps are on many accounts the most remarkable features of the ocean shore line. They probably represent a larger share of solar energy applied through organic life to constructive geological work than is shown by the coral reefs; this is certainly the case if they play the same part along all the northern seashores that they have along the coast of New England. In the methods in which the work is done, in the beauty of the successions of growth, the exquisite symmetry of the system of irrigating canals in the completed swamp, they are not exceeded by the architecture of the coral reefs, admirable as those structures are.

The marine swamps may in their constructive work be well regarded as the complement of the destructive effect exercised by the celestial energy along the shore. The waves (the product of the solar heat) and the tides (the product of the gravitation impulse) bring about the destruction of the exposed portions of shore against which their movements act with destructive energy. A portion of the celestial force operating through organic forces constructs a system by which this wasting is in part compensated and the balance of land and sea preserved. Through its action the fjords are gradually closed and the indented coast is brought again to the form of straight shore lines.

The aggregate work performed by the plant and animal life in constructing the marine marshes and tidal mud-flats along the New England shore is very great. The total area of the true salt marsh lands doubtless exceeds 200,000 acres. The average depth of the deposit, as determined by some score of observations, may be taken at 6 feet. Thus the total mass of the upper or true marsh amounts to about one-third of a cubic mile.

Besides the upper marshes, which in fact constitute only a small part of the work done by organic life on the New England shore, we have the mud-flat and eel-grass layers. These together form a deposit which has an area of at least 300,000 square miles and an average thickness of at least 12 feet. Observations on the thickness of this deposit are not sufficient to determine its thickness with accuracy. It may be found on the average to exceed 20 feet in thickness. Taking the least measurement which can be assigned as the thickness of the mud-flat and eel-grass layers, we have a total mass for the deposit amounting to nearly a cubic mile, which, with the deposit composing the upper marsh area, makes an aggregate of about 1⅓ cubic mile.

The above total does not include the materials gathered in these deposits which have been swept out to sea and deposited beyond the eel-grass layer. No basis exists for computing this matter, but it is evidently a large amount; it may much exceed that which remains in the deposits.

Although only a part of the matter contained in the above-mentioned beds is really of organic origin, the whole owes its position mainly to the work of organic life.

ECONOMIC PROBLEMS CONNECTED WITH MARINE SWAMPS.

A portion of the facts connected with marine swamps has a definite economic importance and will therefore be treated under this head. This matter is divisible into two branches: first, the effect of these swamps on the harbors of the coast line; and, secondly, the use of these swamps for agricultural purposes.

It is a well known fact that nearly all the harbors of all coast lines are subject to a gradual filling by the incoming sediments. When the winds blow toward the shore the waves urge the detritus which they carry farther in toward the recesses of the shore. When they blow from the shore the waves have so little transporting power that they do not return the detritus back into the sea.

The return of this detritus to the sea, if accomplished at all, is brought about by the action of the tide. The tidal action is more effective in transporting sediment from the harbor to the sea than in the reverse direction, because the slopes of the sea floor are to the seaward. The reader will readily perceive this fact by considering that if equal amounts of force are applied to rolling a ball alternately up and down a slope twice a day for many thousand years, although the slope be of very slight declivity, say less than one degree of inclination, it is evident that there will be a constant tendency of the ball to work in the direction in which the surface slopes. This is essentially the condition of the sediments in our harbors; they lie on surfaces which slope to the sea ward and the tide meets with a little more resistance in urging them up these slopes than in dragging them downwards. There is an additional though variable tendency to a seaward movement of the sediment, due to the efflux of the land waters. This is particularly evident in the case of narrow fjords like that of the Hudson, through which a large stream discharges its waters into the sea, but in most cases the influence of the land waters in the scouring of the harbor is small. In Boston Harbor, for instance, the rivers, though of some size, have little scouring effect except in their own channels.

Thus we see that the amount of tidal flow which passes through the water-ways of a harbor is a matter of great economic importance; anything which serves in any way to diminish the volume of the tidal flow may give the persistent waves a chance to close the harbor with the sediments they are constantly urging into it. This importance of the tidal flow in the regimen of our harbors has long been recognized. The commissioners in charge of the most important ports take great pains to guard their tidal basins from infringements which may lessen the volume of water which passes through the important channels; they do not allow any of the areas flowed by the tide to be filled unless an equal water-storage area is provided by excavations. It has been found by experience that the extensive filling of tidal flats in the days before the harbors were properly controlled by law had a decided tendency to shallow the water in the ways by which the tidal wave passed to and from the sea.

These experiments, as well as the theory of tidal action, make it plain that the extensive accumulations of the salt-water marshes must exercise a great influence on the scouring action of the tides, and that this tendency must generally be to diminish the energy of their work.

There can be no question that the restriction in the tidal area due to the formation of the marine swamps has greatly contributed to the filling up of the harbors in which they have been formed. In the system of inlets about Boston Harbor nearly one-half the total original area has become occupied by these swamps. The average original depth of the water on this marsh-covered area at high tide was probably not less than 20 feet. At the present time the depth of water at high tide will not average much over a foot.

Thus there is about one-half less tidal flow through the inlets of the harbor than existed when the shores attained their present position. As will be seen from the list of the tidal marine swamps given in the last part of this memoir, or as can be better judged from an inspection of the admirable Coast Survey chart of the New England shore, these swamps are most apt to form in the more interior parts of the fjords, where they are in a position to do the most in diminishing the flow of the tide. Unless the rapid growth of these marshes is restrained by artificial means they will in time diminish the depth of the water in all the harbors where they are extensively developed.

The rate of growth of these marine marshes is not determined. At the few points where I have been able to get any observations upon it the conditions had been so perturbed by recent artificial changes in the run of the currents that these observations have no value in reference to the normal advance of the shelf on the shallow water. It is evident, however, that the growth is on the average extremely rapid, for the reason that at many points the front of the sheet of the upper terrace has gone forward from 5,000 to 10,000 feet since the growth began. At present, however, the growth is evidently much slower than in the past, for the reason that the shallow-water areas have been generally covered by the marsh growth, and the further advance is resisted, not only by the depth of the remaining areas, but by the friction of the tide against the border of the upper terrace.

In a certain way the growth of these swamps may be regarded as preservative of the harbors. The inorganic matter which is employed in their construction is that which is brought into the harbors by the tidal currents or washed from the neighboring shores; this material alone would accomplish a great shoaling of the water. The growth of the upper marsh shelf against the tidal current, as before described, causes the main tidal ways which traverse the marshes to retain at least their original depth and in some cases to scour out much deeper channels than they at one time occupied. In this way the navigable inlets of the Charles, the Mystic, the Saugus, and other rivers have been formed and maintained, where if there had been no constriction of their ways these inlets would at low water have had no definite channels.

Thus it may be said that while the salt marshes tend on the whole to destroy harbors they also tend to develop and preserve certain narrow channels through which the water which nourishes and extends the morasses finds its path. In a word, their tendency is to convert broad harbors into narrow channels.

We now come to the second economic consideration, viz, to the problem of gaining these marshes to the use of man. This question can only be set forth in a very general way, for the complete discussion of the matter would require an extended treatise. It should at the outset be noticed that the utilization of these deposits for agriculture is by no means a new problem; essentially similar areas in Northern Europe have been extensively reclaimed. A large part of the agricultural grounds of Holland and extensive areas in other northern parts of Europe were originally in the condition of the salt marshes and mud-flats of our Atlantic coast. As has been already indicated, extensive areas of these deposits have already been won from the sea along the shores of the Bay of Fundy. Not less than 60,000 acres of such reclamations have been made during the last century in that part of the American coast. Some experiments have been made in winning these grounds to agriculture along the New England coast, but in most cases they have been limited to the simple task of bettering the natural drainage, so that the marsh hay which they produce could be more easily harvested. Where efforts have been made to exclude the sea and actually till the land they have sometimes been unsuccessful, owing to the failure of those who carried on the trial to see the true conditions of the work. It is very much to be regretted that these experiments were not directed by some one trained in the work as it is effected on the northern shores of Europe, who could have brought to the task the accumulated experience of centuries; if this had been done it is tolerably certain that the process of turning these American marshes to agriculture would now be well advanced.

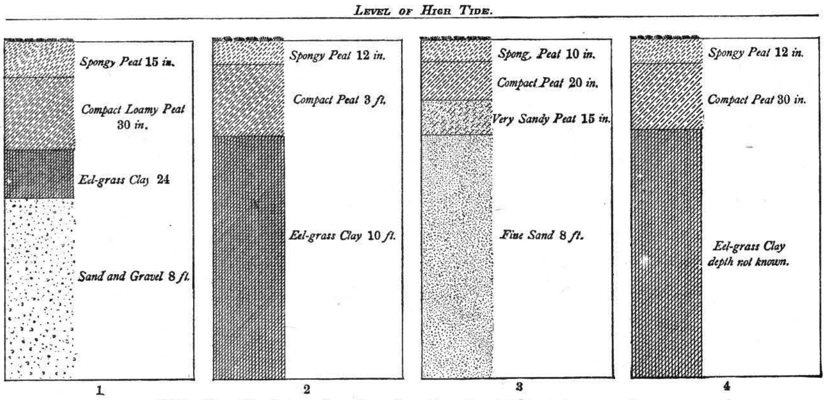


FIG. 54.—Sections showing the structure of marine marshes.

1. Saugus marshes. 2. Charles River marsh. 3. Plum Island marsh, north end. 4. Plum Island marsh, south end.

In considering the fitness of this extensive area for the uses of agriculture we should first notice, once again, the fact that the deposits generally consist of three distinct levels (see Fig. 54): first, the eel-grass level, which is too deeply buried in the water to make its winning to dry ground possible in the present state of our agriculture. Next higher come the mud-flats; a part of this deposit is generally within limits of height which make its redemption possible. A very large amount of these mud-flats lies within six feet of the high-tide level. In the area from Portland to New York probably more than one-half of the mud-flats lie within that limit of height. It is only when this mud-flat level has grown to within about 5 feet of the high-tide mark that the upper terrace succeeds in covering it.

Thus a general section through the whole marine marsh—including that formed in the eel-grass, that formed when the deposit was made on the mud-flat, and finally the last formed and highest salt marsh proper—is made up of three sections, which have a decided diversity in their character: the lowest deposit is generally of a clayey nature, though it is often mingled with sand or pebbles and marine shells; the section formed on the mud-flat is composed of clayey materials, but it generally contains more vegetable and animal matter than the lowest-lying mass. The latter deposit is mainly composed of the part of the upper terrace which is broken up by the waves. This middle or mud-flat part of the section has every element necessary to form a very fertile soil as soon as the salt with which it is charged is decomposed. The upper layer, or shelf, of the salt marsh contains a good deal of clay and much animal organic waste, but its principal component is vegetable matter. This carbonaceous matter varies in a diminishing ratio from the surface downward. Six inches from the surface the average of several analyses taken from different points near Boston, Mass., gives about 50 per cent. of carbonaceous matter, while at three feet from the surface the amount probably does not exceed 20 per cent. This part of the marine marshes evidently contains far too much vegetable matter, at least in its superficial layer, to make a satisfactory soil. The proportion of common salt is also excessive.

If the process of winning these lands from the sea is to attain a full measure of success, it must take account of these features. Steps must be taken to get rid of the superfluous vegetable matter by permitting it to rot and time must be given and the conditions made favorable for the decomposition of the salt or for its washing away by the water. In all the experiments hitherto tried on the New England shore, the farmers seem to have expected that immediately on the fencing out of the sea that the land would be fit for the plow and for the planting of any crop. In practice they have sometimes found that the first result was to destroy the value of the marsh for its natural crop of salt grasses, while, for some time, it was unfit for the growth of the land grasses or, in fact, for any other valuable crop except oats. Deep plowing, underdrainage, and the necessary patience with the process of changing the conditions of the soil have usually been wanting in these experiments.

In an effort to win these soils to the plow the farmer would do well at the outset to select those parts of the area where the upper terrace deposit is the thinnest, not, as has always been done, choosing those places where the level of the marsh was the nearest to the high tide line. A general determination of the depth of the less tillable upper terrace can easily be made by means of simple observations on the altitude of the mud-flat which lies outside of the upper marsh. The upper element may be assumed to extend downwards to the level occupied by the top of the mud-flat. This may be verified by the proper borings, which may be made with the implement known as a post-hole auger or by any other means. The proportion of vegetable matter may easily be determined with sufficient accuracy by burning a pound of the material, weighed after it has been dried in an ordinary oven, then heating the same to redness in an iron vessel upon a fire, and afterwards reweighing the mass. If the amount of vegetable matter does not exceed one-half the total weight for the upper two feet of the section, as will be the case if the weight of the mass does not diminish by more than 50 per cent. under this treatment, then the upper swamp can easily be brought into a condition for cultivation. If the proportion of vegetable matter much exceeds this amount, the difficulties of bringing the surface into a good shape for tillage will be increased.

The first aim of the cultivator should be to make sure of the exclusion of the sea. This can generally be effected in the following manner:

Where the lands are not open to the broad water, a simple closely-set row of stakes or piles should be driven two feet or more into the earth. These stakes should rise at least two feet above high-tide mark, and more if the waves from the open water make additional height necessary, and they should be sheathed by planking on the inner side. Behind them there should be a stout rampart of sods and earth, the sods being placed against the close-set stakes and on the inner side of the barrier. This rampart, if its height be 6 feet, should have a base at least as great as its height. It may advantageously be secured on the inner side by means of planking or a row of stakes for a portion of its height. Such a simple dike will serve for most small areas when the barrier is not much exposed to the action of the waves.

Well-constructed automatic sluices should be provided for the escape of the land waters, so arranged that the ordinary level of this water should not come within three feet of the level of the soil, and, if possible, as much as five feet of clear elevation above the standing water should be attained. Sufficient catch pools should be provided for the reception of the land water during the time when the tide is too high to permit its discharge. This can usually be contrived, without the expense of excavation, by inclosing a portion of the open channels that traverse the marsh or parts of the low-lying mud-flats always bordering the swamp on the sea side. If the expense of this work is to be considerable it will in all cases be desirable to have the dike planned by a competent engineer. These suggestions are meant rather for the guidance of those who desire to make small experiments than for those who intend to undertake large enterprises of this nature.

Having secured the area from the invasion of the sea, the next care of the cultivator should be to bring about the most rapid decay of the vegetable matter contained in the uppermost part of the marsh and the decomposition of the salt which it contains. This will, in the course of years, be accomplished by the natural process of decay; but the process proceeds slowly unless it is hastened by artificial means. The spongy character of the marsh causes it to hold moisture in a firm way, and as long as it is moist its decay is retarded. Deep plowing is therefore an indispensable requisite in the process of betterment.

After a year of exposure the upturned ground will commonly be fit for crops of oats, but it will be at least three years before the surface will be found in condition for general tillage.

Those who undertake the improvement of our swamp lands will do well to limit their work at first to a small area, not exceeding a few acres, so chosen as fairly to represent the general conditions of the reclaimable areas and to avoid the difficulties which come from the invasion of the land waters in times of flood. Wherever there are large areas of marshes there is a great field for selection in this regard. The experience gained on these limited fields may then be extended to larger areas.

The principal difficulty which will have to be encountered in utilizing our American marshes for agriculture will arise from the excessive rain at certain seasons. Where the tide has a fall of less than six feet this difficulty can generally be met by the use of storage basins with sufficient exit ways to be automatically opened in the low state of the tide. On the more southern shores of the United States — all those in the region south of the Delaware Bay — it is likely that any effective work of drainage will have to be connected with a more costly method of removing the water by means of windmills operating pumps, as is now done in Holland and elsewhere in Europe. This is perhaps not practicable in the present condition of American agriculture, and may not be so until the increase of population puts a higher value on tillable ground. Still these southern salt marshes and mud-flats constitute a most valuable reserve of lands which will hereafter be won to man's uses.

The great advantage of the more northern marsh areas is found in the fact that they are generally near the larger centers of population of the country, where they will have a high value as market-garden soils or fields for the raising of hay. When brought into their best state such areas will, measured by the price set upon other lands in the same neighborhood, have a value of not less than $200 an acre. As the total reclaimable area between New York and Portland probably exceeds 200,000 acres, the money value in their best state will amount to at least $40,000,000. The cost of reclaiming these areas and reducing them to cultivation should not exceed the fifth of this sum.

It may be noted that from the chemical composition of these soils they are practically inexhaustible and that from their position they are often well placed for irrigation.

South of the New England shore the marsh area is much more extensive than in that region. It is probable that the improvable marshes of the Atlantic coast amount to at least 3,000,000 acres and they may exceed double this amount. As yet too little is known of their conditions to make it worth while to discuss their prospective value, but it is evident that they are well worth a serious inquiry.

DETAILED ACCOUNT OF SELECTED AREAS OF SALT-MARSH LANDS.

It has not seemed desirable to give a detailed description of the marine marshes which are noted in the following catalogue. The descriptions given below concern only two of the most important areas. That describing the Plum Island marsh is given because the marsh in question is the largest connected area of such land on the New England shore as well as one of those most favorably placed for improvement. The account of the Green Harbor rivers is warranted by the fact that it has been the seat of the most important experiment in winning these marshes to agriculture which has been essayed on any part of the shore north of New York City.

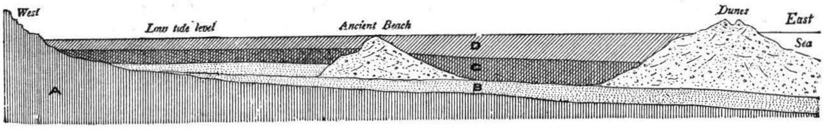
PLUM ISLAND MARSHES.

The Plum Island system of marshes near Newburyport, Mass., is perhaps the largest of any of the swamps of this description which exist north of Long Island Sound. If we take into account the connected areas of marine swamp lying to the north and south of those on Essex, Ipswich, and Hampton Rivers, the total area is more considerable than any other of the northern salt marshes, amounting in all, as will be seen from the appended catalogue, to over 20,000 acres.

It is worth while to give some special attention to this Plum Island district, for the reason that it shows more perfectly than any other area in New England the general way in which these structures are formed.

Any general map of New England will show that this district lies at the innermost part of the Bay of Maine, a deep re-entrant of the coast between Cape Ann and the mouth of the Bay of Fundy. The shores of this great bay were at the close of the glacial period deeply covered with detrital matter, which has been in good part swept into the sea. In part this work of removing the glacial waste to the sea was accomplished during the gradual retreat of the sea immediately after the close of the glacial period; in part it has been brought about by the action of the waves and tides upon the shore since the close of that time. In this region there has also been an extensive cutting away of the drumlins, till, and terrace drift since the sea acquired its present level. The sea to the eastward of this shore abounds in shallows which were probably land areas above the level of the water for a time after the close of the last glacial period, but have since that time been worn away by the waves. From these various sources the sea acquired possession of a large quantity of sand, which has served to shallow its bottom to the point where the waves, in periods of violent storms, could urge this sand towards the shore; the waves acting on the shore and the currents which they induce have served to convey a large amount of this sandy and pebbly matter to the bottom or most re-entrant part of the gulf.

The first result of this action was the shallowing of the water for a mile or two from the shore to a depth which made it possible for the waves to break in periods of great storms. This created a barrier beach along this part of the shore from Little Boars Head to Annisquam River, a distance of about 22 miles. As will be seen from the Coast Survey chart, this portion of the shore forms a gently re-entrant curve; only at one or two points, as at Great Boars Head, does the mainland break upon the continuity of the barrier beach. The only considerable interruptions to the continuity of this beach were formed by the action of the tidal and land waters, which, during the growth of the barrier, kept open several exits. These are at the mouth of Essex River, Ipswich River, and Merrimac River. At present there are only four of these inlets through the beach. There may have been more of these inlets before the scouring action of the tide was diminished by the lessening of the inclosed water basins through the formation of the peat marshes. As this space for the tidal waters diminishes, the outgoing mass of water becomes less and less able to maintain an open way against the sand, which is constantly heaped across its path by the action of the waves. One such exit has recently been closed—that at Hampton Beach—and that at Hampton Harbor is in danger of closure. When this closure of an exit occurs, the imprisoned waters are driven to find a way through the neighboring openings to the sea.



A. Bed rock. B. Sand and gravel. C. Eel grass layer. D. Upper marsh.

FIG. 55.—Diagrammatic section through Plum Island.

When this barrier beach was first created it seems to have been imperfect and much nearer the shore than at present. There are slight traces of such an ancient beach visible at various points in the marsh ground. When the outer beach was formed these original barriers seem to have been reduced to the level of the marsh by the action of the wind; they are now brought down to about the sea level, and are only indicated on the marsh by a slight ridge in the swamp area or the worn-down remains of the dunes dug out to their bases by the winds.

The formation of the marshes seems to have begun immediately after the formation of this outer or existing beach. The time when this ridge began to form cannot have been very remote; for, although it is widening with great speed, it has not yet attained to a width of more than a thousand yards, except in the extreme southern part, where it is a few hundred yards broader.

As the dune mass grows by accumulations made on its seaward face it loses on the landward side, the sand being blown over the surface of the salt marshes. At certain points this blown sand forms a considerable element in the marshy matter.

It is probably to this cause that we owe the shallowness of the streams within the area of the marsh, which are notably less deep and have more sandy bottoms than those at other points along the shore. These sand invasions are particularly conspicuous on the northern end of the Plum Island marshes, near the line of the turnpike which connects the island with the mainland. Here the marsh is not over 2 feet in depth, and a considerable portion of this shallow deposit is composed of sandy matter.

The Plum Island marshes are very well placed for utilization: not only is the area very large, including many thousand acres, but the channels which traverse the area are, on account of their shallowness, but little used for boat harbors or any other purpose. The fresh water which pours through them is small in amount. The dam required to shut off the sea would not be costly when the area reclaimed is considered. The length of the dam required at the southern end will not exceed 3,000 yards; the dam at the northern end is already made by the embankment of the Plum Island turnpike and only requires flood-gates to control the water in channels about 200 feet in width. The greatest depth of water at high tide on the line of this dike will not exceed about 20 feet, and this for only a small part of its length. The average required height of the dam will probably not exceed 10 feet; an abundance of clay for the structure could be found immediately at the western end of the proposed dike. Its construction will be by no means a difficult engineering problem. The water storage spaces within the area are so large and the places for exit sluices are so extensive that it will be possible to lower the level of the water at least 5 feet below the surface of the marsh.

There is perhaps no point on the shore north of New York where so large an area could be secured from the sea at so slight an expense and with so small an effect on the harbor interests of the coast. The flow from these marshes through the exit of Plum Island River is small in quantity and in the main occurs in the first hour or two of the ebb. It is only at the Ipswich channel that any damage to important harbors could occur. There would undoubtedly be certain changes in the altitude of the sand-bars at this point in case these Plum Island marshes were barred from the tide, but how far these changes would affect the depth of water at the entrance to Ipswich River it is not easy to determine. It seems evident, however, that the injury to this port would be more than counterbalanced by the addition of this great area to the agricultural value of the district in which it lies. The present agricultural value of these marsh lands does not exceed about $10 an acre, or a total of say $150,000; if they should become worth $200 an acre they would represent a value of $3,000,000 and would maintain an agricultural population of about five thousand souls.

It should be noticed that the Coast Survey map includes only about three-quarters of the total marine marsh area which would be recovered by the proposed improvement.

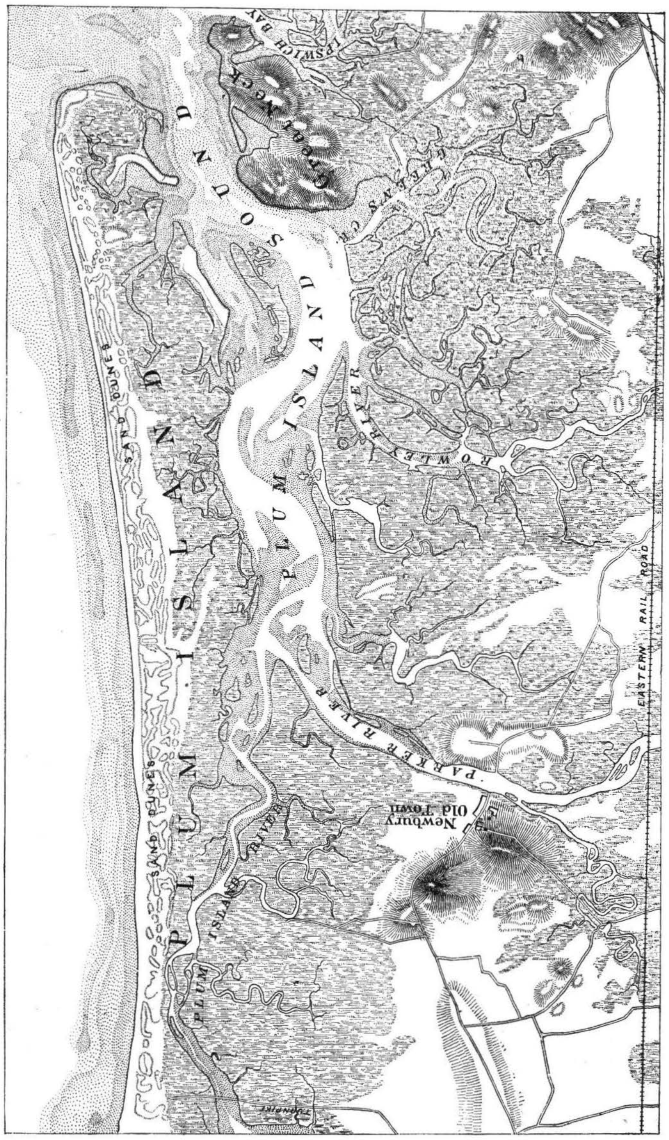


FIG. 56.—Plum Island marshes.

GREEN HARBOR RIVER DIKED LANDS.

The diked lands of Green Harbor River (or Cut River, as it is sometimes misnamed), in the town of Marshfield, Mass., constitute the most extensive experiment in the improvement of marine marshes which has been undertaken in New England. Although, as will be seen below, this experiment has been carried on under somewhat exceptional conditions, the results are of great value from the light which they throw on the general economic problems involved in such enterprises. The Green Harbor River marshes cover an area of about 1,250 acres. They are separated from the sea by a barrier beach, formed by the action of the waves in the manner indicated in the first section of this report. From an early day, perhaps from the time of first settlement of this district by Europeans, in the seventeenth century, this beach was so continuous that the water found a difficult entrance to the marshes through channels leading in from Duxbury Bay. Thus, although these marshes had originally been in free communication with the sea, they had for many years been so far shut off from the incursions of the salt-water that at points farthest from the ocean the swamp had become brackish and many land plants could find root on its surface; moreover, the friction of the incoming sea-water in its tortuous channels was so great that the highest tides did not completely cover the area of the marshes.

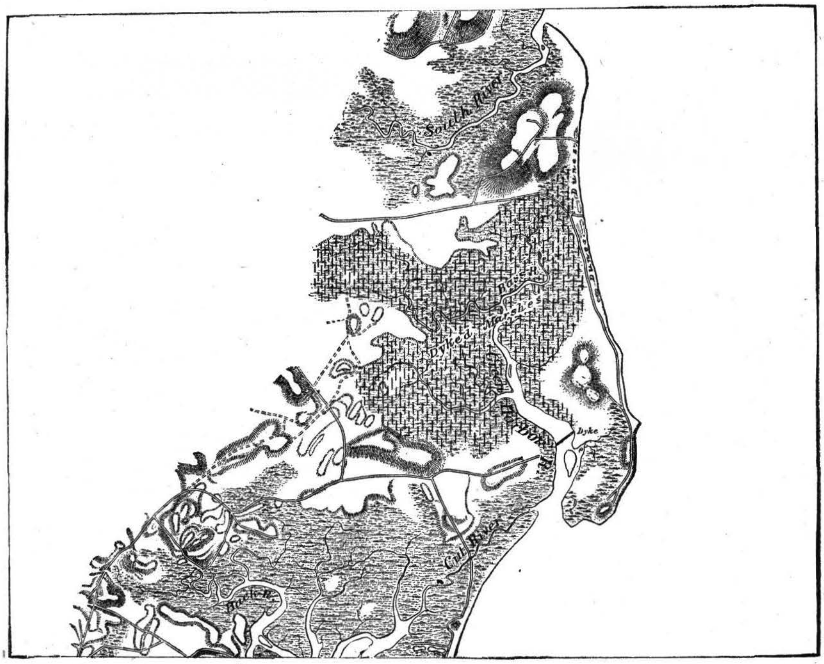


FIG. 57.—Green Harbor River diked marshes. From Coast Survey charts Nos. 109 and 110. Scale, $\frac{1}{80000}$.

In 1810 a channel was cut through the sea wall at the point where is now the entrance of Green Harbor River. This entrance was quickly widened by the action of the tide, so that the sea speedily recovered all of the ground from which it has been partly excluded for some years. It is likely that this cutting merely reopened an inlet which had been closed by the action of the sea; it must have been a very low barrier, for, according to tradition, it was cut through in a night by a party of fishermen. The low nature of the sea wall clearly indicates that there was originally an inlet at this point.

The result of this opening of the swamps to the readier incursion of the tide was at once to narrow the limits of pasturage lands along the shore of the marshes, to the detriment of the farmers' interests. After many years of debate, it was determined to apply to the legislature for authority to close the reopened inlet. This was granted, and in 1872 the dike was constructed at the expense of the adjacent landholders, a tax for its construction being laid upon all those whose lands were to be benefited by the improvement. At the time the project was essayed the lands were, to a great extent, held by persons who were unable or unwilling to meet the cost. The swamp lands were then valued at an average of not more than $5 an acre, those best situated selling for about $15 an acre. Such was the doubt concerning the issue of the undertaking that a large part of the owners sold their holdings to persons who bought them on speculation. The dam was built at a greater cost than the needs required, the total expenditure for it amounting to about $30,000. It proved entirely successful in keeping out the sea, but the sluice-gates were not large enough to lower the level of the waters in the marsh to more than 4 feet below its surface, while 6 feet of lowering was desirable. No system of side ditches was undertaken, although they were imperatively required for the proper draining of the great area of the swamp.

The effect of this exclusion of the sea was immediately perceptible. In one year after the completion of the dike a small portion of the land was sowed in English grass, without any plowing of the ground whatever; the second summer from the time of sowing—i. e, three years from the time when the salt water was excluded—this land gave excellent crops of hay.

Immediately upon the exclusion of the sea, the small anchorage at Green Harbor village, which had served the needs of a few fishermen and gunners for water fowl, began to silt up owing to the fact that the outgoing tide from the interior marshes no longer scoured out the channel. Although the economic importance of this change in the little harbor was slight, it led to a conflict in the courts, which was decided in favor of the owners of the dike. Some of the fishermen then endeavored to remove the dike by force; twice the timber part of the dike at the sluice-way was blown up with dynamite, once in an effective manner. A third effort was frustrated, and a man is now under bonds for trial for the offense.

The result of these regrettable conflicts has been to retard the work of culture of these lands, which have been fairly won from the sea and are secure from all natural dangers. Only about 100 acres of this area have actually been brought into tillage, and this in a very imperfect manner; the farmers, all men of small capital, are naturally unwilling to venture expense in subjugating and planting lands which may be flooded whenever a miscreant succeeds in breaking down the barrier which protects them from the sea. The speculators, who control a large part of the lands, are holding them for the price which they may expect to obtain when the dam becomes well secured against molestation. At present this barrier has to be guarded day and night by watchmen.

The work of tillage has already shown that the expectations of gain from the improvement were well founded. Although none of the land has been properly ditched and the plowing has been of a very poor sort, excellent returns have been won from the soil.

The crop requiring the least tillage is hay; this is said to yield as much as two tons an acre at the principal cutting, even in areas where the soil has received no plowing or other care. It is said that on well-prepared land much larger yields have been obtained. With a slight plowing, the following crops have been planted and have yielded returns as follows: Oats, 45 bushels to the acre; rye, 40 bushels per acre; wheat, said to yield well, but amount not determined; maize, a variable crop on account of its intolerance of salt, but 75 bushels to the acre have been harvested; of onions, large crops are obtained, but the quantity to the acre has not been determined; potatoes yield large crops.

I cannot ascertain that any crop has as yet failed to show a fair promise in this soil.

The criticisms that are made on the soil are that it is rather wet and that the light top mold is apt to wash away, leaving the tough roots of the dead salt-marsh grass exposed. This latter difficulty seems only to be met where the soil has been planted in grass without any tillage, and is doubtless avoidable by a proper system of plowing. The former difficulty is clearly due to the absence of proper ditching, as is shown by the fact that the land within 100 feet of a ditch is generally dry enough for all needs, despite the fact that the water level is never more than about four feet below the surface of the land and is often within three feet of its level.

The principal point in the economic problem has thus been satisfactorily determined by the experience in these improvements; the land has proved fertile and tillable. The ordinary crops of the country do well upon it, and their growth promises to prove more and more satisfactory as the ground is longer tilled. The elements of difficulty which have been encountered are in good part unessential, though they have a very distinct bearing on the management of such enterprises in the future. There has throughout been a great lack of business skill in the management of this property. If the work had been in the hands of a strong company, success would have been attained sooner than it has been. The dam probably could have been built at less expense, and the water could by proper sluices have been kept at a lower level. The lands would have been sufficiently ditched, and it would probably have been found advantageous to plow them once by steam-power, thus breaking up the mat of grass roots which make plowing by the ordinary means a difficult process. Above all, such a company would have given a measure of security against willful injuries to the dam, which it is not easy to effect under the present management. Again, the company might have found it well to bring upon the ground agriculturists from the Netherlands, or other countries, who are familiar with the use of such lands, thus winning some of the experience in a work which is unfamiliar to New England farmers, but is well known to those of Northern Europe.

Some of the promoters and owners in this improvement estimate the original value of these lands at $5 an acre and the present value at $250 an acre. The latter estimate, though apparently high, seems fairly to be based on the crop returns. To secure on the best upland soils of the neighborhood yields similar to those won from the unmanured marshes requires, it is said, the expenditure of at least $25 per annum in manures. If this be the case, and if, as seems likely, the marshes can be cropped for twenty years or more without fertilizing and with no greater expenditure of labor than is required in the uplands, their lands, when properly prepared for tillage, should have at least the value above assigned to them.

If the preparation of this area of marshes had been carefully conducted, the dike would probably have cost not over $15,000; the ditches properly required for the beginning of systematic tillage, about $30,000, or a cost of about $40 per acre, to which, if we add the original value of the land, we shall still have a cost of less than one-fifth its estimated value.

An examination of the area of marshes shows some interesting features, which have a distinct bearing on the problem of winning similar grounds to tillage. It is evident that a certain amount of subsidence has occurred from the decay in the vegetable matter in the mass. It is not easy to determine the average amount of this change in level, but it probably amounts to somewhere near 8 inches over the whole surface. It is likely that it will increase to about double that amount.

On examining the untilled part of the swamp, it is clear that the salt tends to work to the surface, especially during a period of drought. There is a distinct coating of saline matter, partly decomposed, disposed in the form of patches over the areas at a distance of a few hundred feet from the natural drains. This is not observable on the tilled portion of the marsh. It is due to the upward working of the imprisoned salt water, which rises to replace the water which is evaporated at the surface. This upward working of the saline matter will doubtless be interrupted by the process of tillage. In a few years the limited supply of salt will be exhausted, especially if the area shall be guarded from any abnormal invasion of salt water, such as was brought about by the recent blowing up of the sluice-ways.

PRINCIPAL AREAS OF SALT MARSHES BETWEEN THE HUDSON RIVER AND PORTLAND, ME.

The following list has been prepared with the view of giving the more important facts concerning the distribution of the areas of salt marshes between New York and Eastern Maine. Unless otherwise stated the estimates of areas are taken by approximate measurements from the United States Coast Survey printed charts. They are in most cases correct within a limit of error of less than one-twentieth of the estimates. The area of the mud-flats, which in the majority of cases are largely the product of the action of the waves in the upper or true marsh level, is not generally given. In the region south and west of Boston this mud-flat area lies within the limits of reclamation, and will perhaps add one-fifth to the area of winnable land in that part of the coast. North of Boston the increased height of the tide makes it a matter of serious expense to defend the lower-lying mud-flats from the sea; still, nearly the whole of their surface in the region south of Portland is far within the limits of the conditions under which such lands have been won in Holland. It is much to be desired that a careful survey of these and the other swamp deposits of the Atlantic coast belt be made. This should include a comparison between the American coast marshes and those of North Europe. It will be well to have these studies include also the similar formations on the Pacific shore.

Besides the areas given in the following lists, which are taken from the Coast Survey charts, there is a considerable quantity of salt marsh land lying farther inland than these maps extend. There are as yet no satisfactory topographic data for estimating this unmeasured area, but from the best accessible sources of correction it seems likely that these unmeasured portions of the sea marshes amount to not less than one-twentieth of the area given below. The measurements as given were made from the printed sheets of the Coast Survey charts by means of a planimeter of French manufacture, maker unknown. The instrument has been repeatedly tested by comparing its measurements with those where other forms of measurement have been obtained. The results have appeared to be more trustworthy than those attainable by any other mode of determining the areas which could be applied.[1]

The position of the areas is indicated by the latitude and longitude; they are likewise designated by the name of the nearest named river or inlet as given on the map. Owing to the obscurity of the divisions between many of these marsh areas it has been found necessary to assume divisional lines; these appear on the original record maps, but they are stated in an arbitrary way in this catalogue. It will be ob-

[1] A careful testing of the planimeter on twenty selected areas has established the probable combined error of instrument and observer approximately as follows: For an area of 40,000 acres, 260 acres; for an area of 1,000 acres, 30 acres.

served that the list stops near Portland, Me., few of the marshes to the east of that line appearing in the catalogue.

The total area of these marshes within the State of Maine is not large and a considerable portion of the coast, viz, from Mount Desert to Calais, is not yet mapped. It therefore seemed unnecessary for the purpose of this memoir to extend the measurements east of Casco Bay. The marsh areas on Martha's Vineyard and Nantucket islands were not measured. On the maps of these districts the marshes are imperfectly designated. They are, in fact, curiously blended with the sand flats, and, owing to the frequent closure of the lagoons in which they are formed, it is hard, in many cases, to determine whether they belong to the salt or to the fresh water group of marshes. Detailed geological reports on these islands are now in preparation; in them the condition of these marshes and their fitness for improvement will be carefully considered. I am indebted to my assistant, Mr. Alfred Church Lane, for the measurements and computations given in the following catalogue.

Catalogue of the larger salt marshes of New England and Long Island, N. Y.

[The word "incomplete" indicates that the marsh extends farther in than the area mapped on the Coast Survey sheet. Where the number of acres is bracketed [ ] it indicates the area including the surface of inclosed water. An interrogation mark ? shows that the accuracy of the measurement is doubtful.]

Number and name of chart.	Latitude.	Longitude.	Locality.	Area in acres.
	° ′	° ′		
107. Seguin Island to Kennebunkport, Me.	43 18	70 34	Wells Village; one-tenth water	1,265
	43 21	70 32	Little River	176
	43 21	70 30	Coast to Kennebunkport	336
	43 21	70 26	Vaughn's Island and neighborhood.	48
	43 22	70 25	Sampson's Cove	16
	43 23	70 25	Goosefair Creek, both branches	304
	43 25	70 23	Little River	272
	43 27	70 21	Back of Fletcher's Neck	128
	43 28	70 24	Saco River	144
	43 30	70 23	South end of Old Orchard Beach	208
	43 33	70 20	Scarboro Beach and Prout's Neck; incomplete.	1,265
	43 35	70 15	Spurwink River	480?
	43 48	70 09	Yarmouth River	32
	43 49	70 09	Cousin's River	64
	43 44	69 49	Morse River and Atkin's Bay	569
	43 46	69 46	East side of mouth of Kennebec	32
108. From Wells to Cape Ann.	42 37	70 41	Squam River; one-half water	[1,376] 688
	42 38	70 45	Essex River; one-half water; incomplete.	2,846

Catalogue of the larger salt marshes of New England, &c.—Continued.

Number and name of chart.	Latitude.	Longitude.	Locality.	Area in acres.
	° ′	° ′		
108. From Wells to Cape Ann—continued.	42 41	70 48	Ipswich River to margin of Green's Creek, bounded by road; incomplete.	2,942
	42 45	70 48	Plum Island marshes (Green's Creek and Rowley and Parker Rivers); incomplete.	9,280
	42 50	70 50	East Salisbury, Black Rock, and Town Creeks to R. R.; incomplete	1,692
	42 53	70 49	Hampton Harbor; incomplete ...	5,076
	42 58	70 46	North Hampton	47
	42 59	70 46	North of Rye Ledge	32
	43 00	70 45	Rye Harbor	269
	43 01	70 41	Pauson's Creek	285
	43 02	70 43	Little Harbor	237
	43 05	70 40	Marsh south of Cutts Island	63
	43 06	70 39	Marsh north of Cutts Island	332
	43 08	70 39	York River	32
	42 59	70 37	Isles of Shoals; estimated	32
	43 10	70 37	South of Cape Neddick; estimated.	47
	43 12	70 35	Near Pond Rocks; estimated	32
	43 16	70 35	Wells Beach; incomplete	253
109. Boston Bay and approaches.	42 19	71 03	Old Harbor, South Boston	332
	42 20	71 04	South Bay; all filled	400
	42 21	71 05	Back Bay; two-thirds water (as it was); incomplete.	2,277
	42 24	71 05	Mystic River to Lynn Pike; one-third water.	[2,515] 1,677
	42 23	71 01	East Boston	176
	42 23	71 00	Chelsea River	1,202
	42 26	70 59	Saugus River, &c	1,487
	42 25	70 55	Nahant	144
	42 26	70 53	Phillips Beach	112
	42 30	70 53	Back of Marblehead; one-half water.	[316] 158
	42 33	70 54	Danvers; incomplete	140?
	42 34	70 49	Beverly farms	80
	42 35	70 44	Manchester	80
	42 37	70 38	North of Eastern Point	112
	42 04	70 40	Back and Cut Rivers	1,107
	42 05	70 40	Bass and Green Harbor Rivers	1,234
	42 07	70 41	South River; incomplete	633

Catalogue of the larger salt marshes of New England, &c.—Continued.

Number and name of chart.	Latitude.	Longitude.	Locality.	Area in acres.
	° ′	° ′		
109. Boston Bay and approaches—continued.	42 09	70 43	North River; incomplete; one-third water.	[2,293] 1,529
	42 11	70 43	Scituate Harbor; one-tenth water	[208] 187
	42 15	70 46	Cohasset Harbor; one-tenth water.	[759] 683
	42 16	70 50	Near Jerusalem Road	112
	42 16	70 51	Near Jerusalem Road; two-thirds water.	[256] 85
	42 17	70 52	White Head Flats	144
	42 15	70 54	Hingham Harbor, Otis Hill; one-eighth water.	[160] 140
	42 14	70 55	Weymouth Back River; one-half water.	[648] 324
	42 14	70 57	Weymouth Fore River; four-fifths water.	[585] 117
	42 15	70 58	Town River and Hough's Neck; one-half water.	[618] 309
	42 16	71 00	Black's Creek and neighborhood; one-tenth water.	[192] 173
	42 17	71 02	Neponset River and Squantum; one-fifth water.	[1,661] 1,329
110. Cape Cod Bay.	42 03	70 38	Duxbury Beach	474
	42 03	70 38	Back River Islands	95
	42 03	70 38	Duxbury shore	190
	42 00	70 42	Jones' River and shore, east to Standish Monument.	316
	41 57	70 41	Between Jones' River and Plymouth.	174
	41 57	70 38	South end of Long Beach	47
	41 51	70 32	Centre Hill Point and southward	95
	41 47	70 30	Bass, Scusset Mill, and Dike Meadow Creeks.	1,044
	41 46	70 28	Old Harbor, Menset, Spring Hill, Dock and Mill Creeks.	822
	41 45	70 26	Cows', Long, and Scorton Harbor Creeks.	459
	41 43	70 22	Scorton Creek and Great Marshes; one-fourth water.	[4,110] 3,982
	41 43	70 14	Rendezvous and Lone Tree and Chase Gardner Creeks.	1,787

Catalogue of the larger salt marshes of New England, &c.—Continued.

Number and name of chart.	Latitude.	Longitude.	Locality.	Area in acres.
	° ′	° ′		
110. Cape Cod ay —continued.	41 45	70 09	Sursuit Creek	158
	41 45	70 07	Quivett Creek, &c., to Brewster	348
	41 48	70 00	Brewster to Herring River, coast marshes.	933
	41 54	70 00	Blackfish Creek and Horse Island.	949
	41 57	70 03	Herring River, Wellfleet	3,416
	42 00	70 03	Pamet River, &c	474
	42 03	70 06	Peaked Hill Bar. The swamp is back of it.	380
	42 03	70 12	Little swamps around Provincetown.	142
	41 49	69 57	Marshes near Town Cove; one-third water.	[174] 116
	41 46	69 56	Near Pochet Island	569
111. Monomoy and Nantucket Shoals to Muskeget Channel	41 46	69 56	Near Life-Saving Station No. 12	190
	41 40	69 57	Near Morris Island	111
	41 40	70 05	Harwich Marshes	158
	41 40	70 09	West Dennis	142
	41 40	70 08	Swan Pond River	269
	41 38	70 13	Pond east of Lewis Bay	190
	41 36	69 58	Wreck Cove, Monomoy	190
112. Muskeget Channel to Buzzards Bay.	41 38	70 19	Back of Hyannis Point	554
	41 38	70 21	West of Centreville Village	142
	41 37	70 25	Osterville Harbor	469
	41 36	70 27	Poponesset Bay	158
	41 34	70 30	Waquoit Bay, east side	16
	41 34	70 33	Waquoit Bay, west side	110
	41 34	70 35	Ponds south of Falmouth	127
	41 25 to 41 32	70 40 to 70 55	Elizabeth Isles; a number of marshes, salt or fresh?	127
	41 34	70 39	West of Falmouth	47
	41 34	70 38	North of Hamlin Point	95
	41 38	70 38	Wild Harbor and Herring Pond Creek.	127
	41 42	70 38	Pocasset Harbor and North Pocasset.	190
	41 44	70 37	Monumet River and south	316
	41 45	70 39	North of Wicket's Island	32
	41 46	70 41	Agawam; one-half water	[95] 48
	41 45	70 43	Johnson's Creek	111

Catalogue of the larger salt marshes of New England, &c.—Continued.

Number and name of chart.	Latitude.	Longitude.	Locality.	Area in acres.
	° ′	° ′		
113. Cuttyhunk to Block Island.	41 32	70 57	Mishaum Point; incomplete	63
	41 32	70 58	Barney's Joy Point; incomplete	32
	41 31	71 00	Allen's Pond	480?
	41 31	71 03	Westport and various islands near by.	1,756?
	41 31	71 05	Acoakset River; incomplete	696?
	41 30	71 07	No name	111
	41 29	71 10	No name	253
	41 33	71 12	Nonquit Pond	127
	41 35	71 12	Back of Sapowet Point	300
	41 29	71 15	Sachuest Beach, Newport	111
	41 29	71 17	Easton's Pond, Newport	111
	41 27	71 19	The Neck, Newport	47
	41 43	71 11	Near Lee's River	47
	41 40	71 17	Popasquash	63
	41 43	71 17	Warren River	47
	41 44	71 20	Nayat Point	79
	41 39	71 20	Prudence Island, northern part	127
	41 38	71 19	Prudence Island, middle part	158
	41 37	71 25	Mainland west of Prudence Island; estimated.	63
	41 27	71 27	Back of Little Neck; ½ water	332
	41 23	71 30	South of Point Judith Pond	490
114. Long Island Sound, eastern part.	41 04	71 55	Great Pond; end of Long Island	285
	41 00	72 03	Napeague Harbor	332
	41 01	72 08	Acabomock	316
	41 20	72 02	Poquonock River	269
	41 19	72 01	Mumford's Cove	79
	41 21	71 57	Mystic River	364
	41 20	71 55	Wamphassuck Point	127
	41 21	71 54	Quanaduck Cove	63
	41 21	71 52	About Wicketequock River	427
	41 19	71 47	Babcock's Pond	332
	41 20	71 43	Quonocontaug Pond	174
	41 22	71 38	Ninigret and Green Hill Ponds	538
	41 23	71 30	Point Judith Pond	474
115. Long Island Sound, middle part.	41 08	72 15	Oyster Pond	886
	41 06	72 22	About Stirling and Greenport	127
	41 05	72 21	Derring's Harbor	16
	41 03	72 20	West Neck Harbor	32
	41 04	72 19	Coecle's Harbor	32
	41 01	72 12	Three-Mile Harbor	127

Catalogue of the larger salt marshes of New England, &c.—Continued.

Number and name of chart.	Latitude.	Longitude.	Locality.	Area in acres.
	° ′	° ′		
115. Long Island Sound, middle part—cont'd.	41 02	72 13	Ely's Brook	79
	41 00	72 22	Jessup's Neck	32
	40 56	72 26	Jessup's Neck, large swamp	569
	41 00	72 27	Cutchogue Harbor	253
	41 02	72 25	Great Hog Neck, east side; two-thirds water.	300
	41 02	72 25	Great Hog Neck, west side	32
	41 03	72 28	Goldsmith's Inlet	16
	41 00	72 35	Mattituck Pond	47
	40 59	72 37	Luce Landing	16
	40 55	72 37	Flanders, Riverhead, Aquebogue	2,182
	40 57	72 51	Wading River	142
	41 13	73 02	Indian River	364
	41 14	72 59	Oyster River	127
	41 15	72 57	Savin River	127
	41 16	72 57	West Haven	47
	41 17	72 56	New Haven	316
	41 17	72 54	West side of New Haven Bay	221
	41 15	72 53	Morris Creek and Farm River	775
	41 15	72 51	East of Saltonstall's Lake; incomplete.	47
	41 16	72 48	Branford Harbor and River; incomplete.	728
	41 15	72 50	Branford Point	32
	41 16	72 45	Around Stony Point	221
	41 16	72 44	East of Stony Point	206
	41 16	72 42	North of Sachem Head	300
	41 15	72 41	East of Sachem Head	127
	41 16	72 39	Guilford Harbor and East River	1,392
	41 16	72 36	South of Madison	111
	41 16	72 32	Hammonasset and Indian Rivers; incomplete.	981
	41 16	72 30	East of Killingworth Harbor	427
	41 17	72 28	Westbrook, Menunketesuck	469
	41 17	72 26	Near Salt Island	79
	41 17	72 24	Oyster River, Saybrook	633
	41 17	72 22	North and South Coves and a little creek above.	648
	41 18	72 20	Lieutenant's, Back, and Blackhall Rivers.	838
	41 21	72 22	Calves', Goose, and Nott's Islands and Ely's Ferry; incomplete.	390

Catalogue of the larger salt marshes of New England, &c.—Continued.

Number and name of chart.	Latitude.	Longitude.	Locality.	Area in acres.
	° ′	° ′		
115. Long Island Sound, middle part—cont'd.	41 21	72 22	Essex; incomplete	158
	41 17	72 17	East of Griswold's Point	158
	41 18	72 15	Near Hatchett's Point	126
	41 18	72 14	Four-Mile River and next creek east.	95
	41 18	72 13	Bluff Island and adjacent	127
116. Long Island Sound, western part.	41 12	*00 56	Back of Charles Island	300
	41 11	*00 53	Stratford, Islands, &c	100?
	41 12	*00 54	Housatonic River; incomplete	158
	41 10	*00 52	South of Stratford	1,582
	41 09	*00 48	South of Bridgeport	300
	41 08	*00 45	Pine and Fairfield Creeks	633
	41 08	*00 44	Southport, Mill River	237
	41 07	*00 41	Green Farms; one-fourth water	{ [443] 332
	41 06	*00 39	Saugatuck River, east bank	63
	41 06	*00 38	Saugatuck River, west bank	332
	41 05	*00 36	Norwalk River	664
	41 03	*00 33	Five-Mile River to Long Neck Point.	380
	41 03	*00 31	Darien River	111
	41 02	*00 29	Stamford Harbor and east	712
	40 58	*00 59	Mount Sinai Harbor	285
	40 55	*00 50	Stony Brook Harbor and East Flats.	474
	40 53	*00 48	Nissequague River; two-thirds water.	{ [633] 211
	40 54	*00 45	West of Nissequague River	206
	40 56	*00 41	Crab Meadow	316
	40 56	*00 37	Northport Bay	111
	40 53	*00 35	Huntington Harbor	32
	40 56	*00 31	Meadows, Lloyd's Point	32
	40 52	*00 30	Oyster Bay Harbor	79
	40 54	*00 26	Mill Neck Creek	300
	40 54	*00 24	Fox Island to Lattingtown	221
	40 54	*00 22	Dosoris Pond	79
	40 52	*00 22	Mosquito Cove	150?
	40 52	*00 18	Prospect Point	63
	40 48	*00 21	Roslyn	32
	40 48	*00 18	Head of Manhasset Bay	127
	40 46	*00 15	Little Neck Bay	237

* Longitude east of New York City Hall.

Catalogue of the larger salt marshes of New England, &c.—Continued.

Number and name of chart.	Latitude.	Longitude.	Location.	Area in acres.
	° ′	°		
116. Long Island Sound, western part—cont'd.	40 49	*00 12	Throg's Neck	127
	40 52	*00 12	Hutchinson's River; incomplete	601
	40 53	*00 12	Along the coast, Rodman to Davenport's neck.	474
	40 54	*00 14	New Rochelle	95
	40 55	*00 15	Delancey Cove	316
	40 56	*00 17	Mamaroneck	221
	40 57	*00 19	Mill Creek	316
	40 58	*00 20	Manursing Island	190
	41 00	*00 21	Port Chester	47
	41 01	00 23	Bush's Harbor	127
	41 02	*00 25	Coscob Harbor	158
	41 01	*00 26	Greenwich Cove	348
118. Southern coast of Long Island, middle part.	41 01	*1 49	Three-Mile Harbor	63
	41 00	*1 45	North West Creek	316
	41 00	*1 42	Sag Harbor	63
	41 00	*1 39	Noyack	95
	40 56	*1 35	Cow Neck and North Sea Harbor	490
	40 54	*1 30	Canoe place	79
	40 54	*1 26	South Port	300
	40 52	*1 28	Tiana	111
	40 50	*1 25	Shinnecock Bay, shores of	696
	40 50	*1 25	Quogue	?
	40 47	*1 17	Around Moriches Bay:	
			Petunk	491
			Between Petunk and Forge River	554
			Front Beach, &c	949
119. Southern coast of Long Island, western part.	40 37	*00 25	Hempstead Bay	4,064
	40 36	*00 28	South Oyster Bay Islands	1,787
	40 39	*00 30	Shore (long. 0° 27′ to 0° 35′) and Great Island.	3,116
	40 37	*00 31	Islands	996
	40 37	*00 34	Jones Beach and adjacent islands	1,755
	40 41	*00 40	Coast inside (long. 0° 35′ to 0° 45′)	1,866
	40 38	*00 40	Oak Island beach and adjacent islands.	2,704
	40 43	*00 45	Long. 0° 45′ to Connetquot Brook	1,487
	40 39	*00 49	Fire Island	253
	40 43	*00 53	Connetquot Brook to Edward's Landing.	712

* Longitude east of New York City Hall.

Catalogue of the larger salt marshes of New England, &c.—Continued.

Number and name of chart.	Latitude.	Longitude.	Locality.	Area in acres.
	° ′	° ′		
119. Southern coast of Long Island, western part—continued.	40 44	*00 56	Brown's Point	206
	40 44	*00 59	Blue Point and Mill's Landing	158
	40 45	*00 59	Patchogue Landing	79
	40 45	*1 02	Swan Creek to Howell's Point	474
	40 46	*1 06	Bellport Bay	886
	40 45	*1 09	Smith's Point to end of chart	712
120. New York Bay and Harbor.	40 45	73 50	Flushing Bay	1,978
	40 49	73 50	Westchester Creek	538
	40 49	73 51	Just west of Westchester Creek	316
	40 49	73 52	Broncks River	380
	40 48	73 55	Mott Haven and Port Morris	601
	40 46	73 54	Near Berrians Island	253
	40 44	73 57	Hunter's Point	1,218
	40 36	73 47	Rockaway Beach	459
	40 37	73 50	Islands in Jamaica Bay	3,732
	40 37	73 50	Coast around Jamaica Bay	11,070
	40 35	74 00	Coney Island	949

*Longitude east of New York City Hall.

SYNOPSIS

OF THE

FLORA OF THE LARAMIE GROUP.

BY

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ILLUSTRATIONS.

SYNOPSIS OF THE FLORA OF THE LARAMIE GROUP.

INTRODUCTION.

The object of this paper is twofold: first, to offer, as its title implies, a synopsis, or condensed account, of the flora of the Laramie group, as that formation is now understood; and, secondly, to give a few illustrations of this flora from new material or from material more ample and abundant than has heretofore existed.

Mr. Leo Lesquereux, in his "Tertiary Flora,"[1] describes a large number of plants belonging to this group, but he here argues for the Tertiary age of these plants and regards the group as Eocene; he therefore makes no attempt to keep them separate from those derived from higher and still acknowledged Tertiary beds. In his last work, on "The Cretaceous and Tertiary Floras,"[2] he attempts to introduce a "table of distribution" of the plants of the Laramie group, but in doing so he fails to recognize the Fort Union forms as belonging to that group, although the identity of the two groups had been admitted by Dr. Hayden in his annual reports and was reasserted in his letter transmitting Mr. Lesquereux's "Tertiary Flora" to the Secretary of the Interior for publication. He preferred to accept the view of Mr. Clarence King (who admitted that he had not visited the Fort Union beds), as expressed in his Report of the Geological Exploration of the Fortieth Parallel, Volume I, pp. 353, 354, and which rested upon the determinations by Dr. Newberry of certain vegetable remains of Miocene type. Mr. King believed this formation to be equivalent to the White River Miocene, and Dr. Newberry referred all his Fort Union plants to the Miocene. The only localities which he admits as constituting the plant beds of the Laramie group known at that date are those of Colorado, the Raton Mountains, Placière, Henry's Fork, Barrel Springs, Fort Ellis, Spring Cañon, Black Buttes, Point of Rocks, and Yellowstone Lake. This excludes Carbon and Evanston, which I shall also embrace in the Laramie, and there are several other localities from which fossil plants have been obtained that belong with little doubt to the same great system.

[1] Contributions to the Fossil Flora of the Western Territories, Part II. The Tertiary Flora. By Leo Lesquereux. Report of the United States Geological Survey of the Territories, F. V. Hayden, United States geologist-in-charge. Vol. VII. Washington, 1878.

[2] Contributions to the Fossil Flora of the Western Territories, Part III. The Cretaceous and Tertiary Floras. By Leo Lesquereux. Report of the United States Geological Survey of the Territories, F. V. Hayden, geologist-in-charge. Vol. VIII. Washington, 1883.

HISTORICAL REVIEW OF OPINION.

The history of the Laramie group, as now understood, is a long one, and the literature is scattered through a series of reports in a manner very perplexing to any one who desires to gain a comprehensive knowledge of it. From the circumstance that at nearly all places where it has been recognized it consists to a greater or less extent of deposits of lignite or coal, this condition was for a time inseparably associated with it to such an extent that there was a disposition to regard all the lignitic deposits of the West as belonging to the same geologic formation; but when this had been disproved by the discovery of extensive beds of coal in the middle Cretaceous, the reaction against this view carried many too far, and resulted in the quite general belief that the lignite beds of the Upper Missouri River were of widely different age from those of Colorado and Wyoming. Even Mr. King, who correlated all the beds along the 40th parallel, and first gave them the name of "Laramie group," still denied the identity of the Fort Union beds with them, and as late as 1878 regarded these as Miocene and the equivalent of those of the White River. It is remarkable that he should have expressed such an opinion in so prominent a place as his final report (Report of the Geological Survey of the Fortieth Parallel, Vol. I, p. 353), while admitting that he had not personally examined this region.

The northern portion of the extensive area now embraced under the name Laramie group was the first to attract attention. It was natural that the earliest transcontinental voyages should follow the largest water-ways, and notwithstanding the extremely slow development of the Upper Missouri River region we find that its exploration was begun in the first decade of the century by parties provided with appliances for scientific observation and has been continued at intervals ever since. Leaving the merely geographical aspects out of the account, we find that the coal beds attracted the attention of Lewis and Clarke in 1803 and of every subsequent expedition down to the epoch of true geologic investigation, which dates from the commencement of the protracted researches of Messrs. Meek and Hayden in the year 1854, the earliest publications of which are contained in Volume VIII of the Proceedings of the Philadelphia Academy of Sciences, 1856. The investigations of Harris and Audubon in 1844[1] added scarcely anything to the knowledge of the geological age of these regions. As much might be said of the explorations of Frémont, who observed the lignite beds of Wyoming in 1842, and of the expedition of General Emory who noted those of Eastern New Mexico in 1848. But the large collections brought by Hayden from Nebraska and the Upper Missouri and Yellowstone regions in 1854 furnished the data for profitable scientific in-

[1] Proceedings of the Academy of Natural Sciences, Philadelphia, Vol. II, 1845, pp. 235–240.

vestigation, which they soon received at the competent hands of Messrs. Meek and Leidy. In the first of the papers above referred to,[1] in which all the species described are mentioned as Cretaceous, the authors remark: "It is worthy of note that some of the species contained in the collection from the most recent Cretaceous beds of the Upper Missouri country appear referable to genera which, according to high European authority, date no farther back than the true chalk, while many of them are closely analogous to Tertiary forms; so close, indeed, that, had they not been found associated in the same beds with Ammonites, Scaphites, and other genera everywhere regarded as having become extinct at the close of the Cretaceous epoch, we would have considered them Tertiary species." A section is given, at the top of which 400 to 600 feet of "Tertiary" are placed, which is described as "beds of clay, sandstone, lignite, &c., containing remains of vertebrata, and at places vast numbers of plants, with land, fresh-water, and some times marine or estuary mollusca."

At the next meeting of the Academy, Dr. Joseph Leidy read a paper in which he described the vertebrate remains which Dr. Hayden had obtained from the Bad Lands of the Judith River. He is silent as to the age which these remains indicate until the close of the paper, where he names a species of Lepidotus in honor of the discoverer, and says: "This species is named in honor of Dr. Hayden, who collected the remains characterized in this paper; and which remains, I suspect, indicate the existence of a formation like that of the Wealden of Europe;" a remark which has since been much quoted in support of the Mesozoic age of the Judith River beds.

On June 10th of the same year a second paper was presented to the Academy by Messrs. Meek and Hayden, entitled "Descriptions of new species of Acephala and Gasteropoda, from the Tertiary formations of Nebraska Territory, with some general remarks on the Geology of the country about the sources of the Missouri River."

These "general remarks," which were "based upon the observations and collections of Dr. Hayden," contain some very interesting statements and certain somewhat remarkable adumbrations of the conclusions to which the latest investigations have led respecting the geology of this region. The lignitic deposits are regarded as Tertiary, but they are very clearly distinguished from the fresh-water deposits of the White River group as well as from the underlying Cretaceous formation. "Although there can be no doubt," the authors say, "that these deposits hold a rather low position in the Tertiary system, we have as yet been able to arrive at no very definite conclusions as to their exact synchronism with any particular minor subdivision of Tertiary, not having been able to identify any of the mollusca found in them with those of any well marked geological horizon in other countries. Their general

[1] Proceedings of the Academy of Natural Sciences, Philadelphia, Vol. VIII, 1856, p. 63. (Read March 11.)

resemblance to the fossils of the Woolwich and Reading series of English geologists, as well as to those of the great Lignite formations of the southeast of France, would seem to point to the lower Eocene as their position." In view of the fact that eminent geologists with abundant material before them have until very recently regarded the Fort Union group as of Miocene age, this early hint at their lower position seems to deserve mention in passing. On the other hand, the extremes to which certain vertebrate remains from the Judith River beds farther up the Missouri had led paleontologists in the opposite direction were fairly anticipated in this early paper. After commenting upon the facts which prompted Dr. Leidy to liken the Judith River deposits to the Wealden of Europe, the authors add: "Inasmuch, however, as there certainly are some outliers of fresh-water Tertiary in these Bad Lands, we would suggest that it is barely possible these remains may belong to that epoch, though the shells appear to be all distinct species from those found in the Tertiary at all the other localities in this region."

In a subsequent paper, read November 11th of that year and published in the same volume (pp. 265–286), yielding to the weight of authority of the eminent paleontologists who had studied the vertebrate and vegetable remains, these authors, in the section drawn up on page 269, place the yellowish sandstones of the Judith in their lowest member of the Cretaceous (No. 1), along with the darker sandstones of the Big Sioux, now so well known to characterize the Dakota group,[1] while the lignite deposits of the Lower Yellowstone and Fort Union region are put at the top of the Tertiary system and designated as Miocene. In an elaborate paper by Messrs. James Hall and F. B. Meek in the "Memoirs of the American Academy of Arts and Sciences" communicated June 27, 1854,[2] a section is given in which the Cretaceous series is subdivided into five members, corresponding substantially with that published in the Proceedings of the Philadelphia Academy by Messrs. Meek and Hayden (Vol. VIII, 1856, p. 269), as also with that which appeared in the same publication for December, 1861 (Vol. XIII, p. 419), and was reproduced in Hayden's First Annual Report of the United States Geological Survey of the Territories for 1867, where, for the first time, the names by which the groups have since become so widely known were attached. In this earliest section of Meek and Hall the Bad Land formation of the Upper Missouri is placed above the Cretaceous series, and is not subdivided but is designated as "Eocene Tertiary" and assigned a maximum thickness of 250 feet.

On May 26, 1857, Dr. F. V. Hayden laid before the Philadelphia

[1] This view seems to have been maintained by Mr. Meek as late as 1860. See Proceedings of the Academy of Natural Sciences, Philadelphia, Vol. XII (April), 1860, p. 130.

[2] Descriptions of new species of fossils from the Cretaceous formations of Nebraska, &c., Vol. V, 1853, Part II, Art. xvii (extras dated 1856).

Academy a rough geological map of the country bordering on the Missouri River, from the mouth of the Platte to Fort Benton, with explanations.[1] According to this map the "Great Lignitic Tertiary Basin" begins at the mouth of Heart River and extends to near the Muscle Shell. It also stretches back on the Little Missouri to near the base of the Black Hills and on the Yellowstone to the mouth of the Big Horn. He also lays down an extensive "Tertiary" tract lying between the South Fork of the Cheyenne and the Platte and extending east and west from the 100th meridian to Fort Laramie. The Judith River Bad Lands are also treated as Tertiary, the too deep coloring of the map being explained in a foot note on page 110. Of the Great Lignitic deposit he remarks that "the collections of fossils now obtained show most conclusively * * * that it cannot be older than the Miocene period." Of the Judith River basin he says that "the impurity of the lignite forms the most essential lithological difference between this deposit and the Great Lignite basin below Fort Union."

Immediately following this communication in the same volume is a more extended one by Messrs. Meek and Hayden, devoted primarily to the description of new paleontological material from the same general region, but containing an introductory discussion of the geological problems involved. Besides sections of the beds above Fort Clarke, and near the mouth of the Judith, this paper gives a general one for the whole of this country, in which the "Tertiary system" is now classed as Miocene.

The first complete section of the "Tertiary" formations of the West was drawn up by Messrs. Meek and Hayden, and also published in the Proceedings of the Academy of Natural Sciences of Philadelphia, for December, 1861 (Vol. XIII, p. 433). The series is subdivided into the four familiar groups: 1, Fort Union, or Great Lignitic; 2, Wind River; 3, White River; 4, Loup River. We are concerned here only with the first, or lowest member of this series, the so-called Great Lignitic. This is defined as "Beds of clay and sand, with round ferruginous concretions, and numerous beds, seams, and local deposits of lignite; great numbers of dicotyledonous leaves, stems, etc., of the genera Platanus, Acer, Ulmus, Populus, etc., with very large leaves of true fan palms. Also, Helix, Melania, Vivipara, Corbicula, Unio, Ostrea, Potamomya, and scales of Lepidotus, with bones of Trionyx, Emys, Compsemys, Crocodilus, etc.; thickness: 2,000 feet or more; localities: occupies the whole country around Fort Union, extending north into the British possessions to unknown distances; also southward to Fort Clarke. Seen under the White River group on North Platte River above Fort Laramie. Also on west side Wind River Mountains."

Although nothing is said either here or in the more general description which follows of the relation of the Judith River beds to this formation, we learn from a foot note appended to page 417 that the

[1] See Proceedings of the Academy of Natural Sciences, Philadelphia, Vol. IX, p. 109.

idea that it could be Jurassic had now been wholly given up by the authors, who had come to regard it as the lower part of the Fort Union group. This note is as follows: "At the time we published these facts, we were led by the discovery here of fresh-water shells in such a position to think that some estuary deposits of doubtful age near the mouth of the Judith River on the Missouri, from which Dr. Leidy had described some saurian remains resembling Wealden types, might be older than Tertiary. Later examinations, however, have demonstrated that the Judith beds contain an entirely different group of fossils from those found in the rock under consideration, and that they are really of Tertiary age, and hold a position at the base of the Great Lignite series of the Northwest."

In discussing this same section in the First Annual Report of the Geological Survey of the Territories, 1867, Dr. Hayden distinctly classes the Judith River basin with the Fort Union group, and says: "This basin is one of much interest, as it marks the dawn of the Tertiary period in the West by means of the transition from brackish to strictly fresh-water types. It is also remarkable for containing the remains of some curious reptiles and animals, reminding the paleontologist of those of the Wealden of England."

By this time the more southern extension of the coal-bearing beds had begun to receive the attention of geologists, and they had been traced into Wyoming and Colorado and as far south as Raton Pass in New Mexico. Fossil plants had been found at nearly all points, and their testimony was considered the most unanswerable for the Tertiary age of the entire group. Indeed, down to 1868, with the single exception of the alleged Wealden facies of the Judith vertebrates, there was substantial harmony upon this point. The array of names of those who had committed themselves to this view after thorough study of the different kinds of fossils is truly formidable, and there can be no wonder that when their position was at length challenged and the Cretaceous age of this great series asserted the conflict of opinion resulting was sharp and the resistance stubborn. Messrs. Meek, Hayden, Lesquereux, and, as Dr. Hayden states,[1] Leidy, all conceded this. Capt. E. L. Berthoud had studied the formation in Colorado and inclined to take the same view.[2] He says: "Everything that I have so far seen points out that the coal is either Cretaceous or Tertiary, but I believe it to be Tertiary, or of the same age as the coal near Cologne, on the Rhine." In an article contributed by Dr. Hayden to the American Journal of Science for March, 1868 (Vol. XLV, p. 198), he reiterates his views in a form that indicates that thus far they had met with no serious opposition.

The first dissenting voice to this general current of belief seems to have been raised by Dr. John L. LeConte, who had investigated the

[1] Annual Report United States Geological and Geographical Survey of the Territories, 1874, p. 21.

[2] First Annual Report United States Geological and Geographical Survey, 1867, p. 57.

coal and plant bearing beds lying along the Smoky Hill Fork of the Kansas River. In his report of a survey of this region[1] he gives it as his opinion that the lignitic strata of this region are older than those of the Upper Missouri, which he admits to be Miocene (p. 65). He states that specimens of Inoceramus were found with the coal in Raton Pass, indicating its Cretaceous age, and then proceeds to adduce reasons for discrediting the evidence furnished by vegetable remains.

The following year (1869) Prof. E. D. Cope, in an exhaustive paper on the vertebrate paleontology of America, published in the Transactions of the American Philosophical Society (Vol. XIV), in commenting upon *Ischyrosaurus antiquus*, Leidy, from Moreau River, Great Lignitic of Nebraska, speaks of that formation as "perhaps of the Cretaceous age" (p. 40), and with more confidence later on assigns *Hadrosaurus ? occidentalis*, Leidy, to the "?Cretaceous beds of Nebraska," although *Palæoscincus costatus*, Leidy, is still kept in the "upper Jurassic Bad Lands of Judith River." In the tabular exhibit at the close of this memoir the first of these species is placed in the Cretaceous column; the second is also placed in that column, but with an accompanying mark of interrogation, while the third is assigned to the Jurassic column.

The Third Volume of the United States Geological Exploration of the 40th Parallel, relating to Mining Industry, bears date 1870, and contains an important chapter (VII) from the pen of Mr. King on the Green River Coal Basin, in which he maintains that the extensive coal-bearing deposits of this region are chiefly of Cretaceous age, but admits that the uppermost strata pass into the Tertiary and become fresh-water beds. He also declares that the true fresh-water Tertiary strata of the Green River group overlie the coal beds unconformably at all points. "The fossil life," says Mr. King, "which clearly indicates a Cretaceous age for the deepest members up to and including the first two or three important coal beds, from that point gradually changes with a corresponding alteration of the sediments, indicating a transition to a fresh-water period. The coal continued to be deposited some time after the marine fauna had been succeeded by fresh-water types. The species of fossils are in no case identical with the California Cretaceous beds, which occupy a similar geological position on the west of the Sierra Nevada. Their affinities decidedly approach those of the Atlantic slopes, while the fresh-water species, which are found in connection with the uppermost coal beds, seem to belong to the early Tertiary period." And, speaking of the unconformity of strata above referred to, he remarks: "Whatever may be the relations of these beds in other places, it is absolutely certain that within the region lying between the Green River and the Wahsatch, and bounded on the south by the Uintah

[1] Notes on the Geology of the Survey for the extension of the Union Pacific Railway, E. D., from the Smoky Hill River, Kansas, to the Rio Grande. By John L. LeConte, M. D. Philadelphia, February, 1868.

range, there is no single instance of conformity between the coal beds and the horizontal fresh-water strata above them."

This chapter also contains a list of the fossil invertebrata collected in that region and named by Mr. Meek, accompanied by an interesting letter explanatory of their geologic significance. The fact that several species of Inoceramus, and some which seemed referable to Anchura, were positively credited to the coal series, led Mr. Meek to speak with the greatest caution as to the age of these rocks; but it is clear that, but for these facts, coupled with the stratigraphical considerations urged by Mr. King, he would have scarcely hesitated to pronounce it Tertiary. But he lays great stress upon "the fact that these fossils are all marine types," and says: "From all the facts now known I can, therefore, scarcely doubt that you are right in referring these beds to the Cretaceous." A paragraph on page 462 gives his reasons for this conclusion more in full, together with certain qualifications which he feels obliged to make, and closes with the remark that the facts seem to indicate "that these beds belong to one of the very latest members of the Cretaceous; or, in other words, that they were probably deposited when the physical conditions favorable to the existence of those forms of Molluscan life peculiarly characteristic of the Cretaceous period were drawing to a close or had in part ceased to exist."

Relative to the age of the so-called Bear River estuary beds, Mr. Meek expressed himself in this communication with still greater reserve. These beds had been referred by him and Mr. Henry Engelmann to the Tertiary in 1860, in a communication made by them to Capt. J. H. Simpson, and published in the Proceedings of the Academy of Natural Sciences of Philadelphia for April of that year (Vol. XII, p. 130). He admits, however, that they may be Cretaceous, as they belong to the lower disturbed system elsewhere regarded as Cretaceous. He says that some of the fossils described by him from the mouth of the Judith River "are identical with those found in these Bear River estuary beds," expresses doubt that the saurian remains from there were really from the same horizon, and concludes as follows: "While I am, therefore, willing to admit that facts may yet be discovered that will warrant the conclusion that some of these estuary beds, so widely distributed here, should be included rather in the Cretaceous than in the Tertiary, it seems to me that such evidence must either come from included *vertebrate* remains or from further discoveries respecting the stratigraphical position of these beds with relation to other established horizons, since all the molluscan remains yet known from them (my own opinions are entirely based on the latter) seem to point to a later origin."

Prof. O. C. Marsh, in giving an account, in the American Journal of Science for March, 1871, of an expedition conducted by him the previous season through a portion of the Green River Valley and Eastern Utah, describes the coal deposits met with by the party on Brush Creek with special reference to their geologic age. He says (p. 195): "As the age of the coal deposits of the Rocky Mountain region has of late been much discussed, a careful examination was made of the series of strata containing the present bed and their Cretaceous age established beyond a doubt. In a stratum of yellow calcareous shale which overlies the coal series conformably, a thin layer was found full of *Ostrea congesta*, Conrad, a typical Cretaceous fossil; and just above, a new and interesting crinoid, allied apparently to the *Marsupites* of the English Chalk. In the shales directly below the coal bed, cycloidal fish scales and coprolites were abundant; and lower down, remains of turtles of Cretaceous types, and teeth of a Dinosaurian reptile, resembling those of *Megalosaurus*, were also discovered."

The gradual acceptance of the Cretaceous character of the coal-bearing series of the central and southern districts did not thus far shake the opinion of geologists as to the Tertiary age of the Fort Union group. This is reaffirmed in a very positive manner in the Fourth Annual Report of the Geological Survey of the Territories, 1870 (published in 1871), by Dr. J. S. Newberry, who had been long and carefully studying the vegetable remains collected near Fort Union and along the lower Yellowstone, and had already published descriptions of the species.[1] At the time this paper was presented there was no difference of opinion and the evidence of the plants was regarded as simply confirmatory of Meek's conclusions as to the Miocene age of these beds.

Further on in this report (pp. 164, 165) Dr. Hayden discusses the age of the Wyoming coal strata, and says: "So far as we can determine, the coal beds of the Laramie plains are of Eocene age, although the plants are more closely allied to those of the Miocene period of the Old World;" and again: "That there is a connection between all the coal beds of the West I firmly believe, and I am convinced that in due time that relation will be worked out and the links in the chain of evidence joined together. That some of the older beds may be of upper Cretaceous age I am prepared to believe, yet until much clearer light is thrown upon their origin than any we have yet secured I shall regard them as belonging to my transition series, or beds of passage, between the true Cretaceous and the Tertiary."

In the same report Mr. Lesquereux discusses the fossil plants from Raton Pass, collected by Dr. LeConte, whose views have already been stated, as well as those brought in from points along the line of the Union Pacific Railroad and from other parts of the West. He considers them all Tertiary and ranging from the Eocene to the Miocene.

In the corresponding report for 1871, published in 1872, Mr. Lesquereux describes a mass of new material, and from all the data at hand essays a number of important generalizations. As he still regards all the localities in the great coal bearing series of the West as belong-

[1] Notes on the Later Extinct Floras of North America, with Descriptions of some New Species of Fossil Plants from the Cretaceous and Tertiary Strata. Annals of the Lyceum of Natural History, New York (April), 1868. (Read April 22, 1867.)

ing to the Tertiary formation, the only point of special interest brought forth is his attempt to subdivide the American Tertiary into subordinate groups based upon the analogies afforded by their floras with those of established horizons in Europe and elsewhere. Thus to the Eocene he refers Raton Pass and Purgatory Cañon, in New Mexico; Marshall's Mine, in Colorado; Washakie Station and Evanston, in Wyoming; and Spring Cañon, near Fort Ellis, in Montana, as well as Yellowstone Lake, which also belongs to the upper district. To the Lower Miocene he refers Carbon Station, Junction Station, Medicine Bow, Rock Creek, and the Washakie group, in Wyoming; and the Fort Union group, in Montana and Dakota. To the Middle Miocene are referred Barrel Springs and Muddy Creek, in Wyoming; Henry's Fork of Snake River; and Elko Station, Nevada. Among the localities the geological position of which is marked as unknown are the important, and now well known ones, Point of Rocks and Green River. In a table of distribution the data are assumed to exist to justify this classification.

Notwithstanding these efforts to sustain the argument for the Tertiary age of the central coal formation of the West, it had been so weakened by the blows of King and Marsh, coupled with the admissions of Meek, that little remained but the evidence afforded by the fossil plants in its support, and this, though abundant in quantity, was naturally distrusted, and had been enfeebled by the considerations urged against it by Le Conte. Meek himself did not hesitate to refer forms of Ostrea and Anomia, from Point of Rocks on the Union Pacific Railroad and in the typical Bitter Creek district, to the Cretaceous,[1] and now there was destined to come forward a new discovery of great importance, the full weight of which fell upon that side of the question. In the summer of 1872 Messrs. Meek and Bannister discovered the bones of a large saurian near Black Buttes Station in the Bitter Creek series, and Professor Cope soon after visited the spot and studied the fossils. He laid his results before the American Association for the Advancement of Science at Dubuque in August of that year, and published his descriptions in the Proceedings of the American Philosophical Society for September 19. In this paper he remarks (p. 483): "From the above description it is evident that the animal of Black Buttes is a Dinosaurian reptile. * * * It is thus conclusively proven that the coal strata of the Bitter Creek Basin of Wyoming Territory, which embraces the greater area yet discovered, were deposited during the Cretaceous period, and not during the Tertiary, though not long preceding the latter." And, commenting upon the same subject in the American Naturalist for November, 1872, he says: "This discovery places this group without doubt within the limits of the Cretaceous period."

Mr. Lesquereux was also in the field this year (1872), and his investigations, at the request of Dr. Hayden, were specially directed to "posi-

[1] Fifth Annual Report United States Geological Survey of the Territories, 1871, p. 375.

tively ascertaining the age of the lignitic formations." He visited most of the important points in Wyoming, Colorado, and New Mexico, and prepared an elaborate report, in which, it is needless to say, he confirmed and reasserted his former conclusions as to the Tertiary age of the entire coal-bearing series, which he denominates the American Eocene.[1]

The reports of Messrs. Meek and Bannister were also published in the same volume. The former expresses himself with his usual caution, admitting that the invertebrate fossils were inadequate to determine the age of this group, and that his former reference of certain species to the Cretaceous was not prompted by the evidence afforded by the forms themselves (pp. 457, 458). Some of the statements made in this report have acquired special interest in the light of recent investigations and in view of the gradual settlement of opinion which seems to be now going on respecting this much discussed question. He says (p. 460): "The most surprising fact to me, supposing this to be a Cretaceous formation, is, that we found directly associated with the reptilian remains at Black Buttes a shell I cannot distinguish from *Viviparus trochiformis*, originally described from the Lignitic formation at Fort Clarke, on the Upper Missouri, a formation that has always been regarded as Tertiary by all who have studied its fossils, both animal and vegetable. * * * The occurrence of this last mentioned species here, along with a Cretaceous type of reptilian, and a *Corbicula* apparently identical with *C. cytheriformis* of the Judith River brackish-water beds, together with the presence of Corbiculas very closely allied to Judith River species, at lower horizons in this series, and the occurrence of some vertebrates of Cretaceous affinities at the Judith River localities, would certainly strongly favor the conclusion, not only that this Judith formation, the age of which has so long been in doubt, is also Cretaceous, but that even the higher fresh-water lignite formation at Fort Clarke and other Upper Missouri localities may also be Upper Cretaceous instead of Lower Tertiary."

From these and other expressions in this report Mr. Meek may be fairly said to have conceded the Cretaceous age of the Bitter Creek series, but he insists that the Judith River deposits must go with it into that formation, while of the Fort Union group his position may be summed up by quoting his remark that it would take very strong evidence to convince him "that the higher fresh-water Lignite series of the Upper Missouri is more ancient than the Lower Eocene."

The year 1874 found the discussion of the age of the so-called American Lignitic at its height. A paper in the American Journal of Science for April of that year, by Dr. Newberry, and a reply to it by Mr. Lesquereux in the same journal for June, deserve special attention. The former makes bold to say that to his "certain knowledge" a considerable portion [that of New Mexico] of the flora which the latter had called

[1]Annual Report of the United States Geological Survey of the Territories, 1872, pp. 339, 343.

Eocene in his last report is Cretaceous, and that another considerable portion [that of the Upper Missouri] is of Miocene age, and he denies that the flora of any part of the American coal series possesses an Eocene facies. Mr. Lesquereux's reply is of course a defense of his former position and is supported by a vast array of facts.

In the first bulletin of the Geological Survey of the Territories, published in 1874, Professor Cope, from evidence supplied by vertebrate remains, refers the Great Lignitic of the Upper Missouri to the same section of geologic time as the Bitter Creek coal series, now settled in his mind as Cretaceous, and in Bulletin No. 2 (pp. 5–19) appeared an elaborate report by the same author (reproduced, apparently without change, in the Annual Report for 1873, also published in 1874 and later than the Bulletins, pp. 431–446), in which he sums up the evidence from the side of vertebrate paleontology. In this report Professor Cope gives Mr. Lesquereux full credit for accurately co-ordinating the data furnished by the vegetable remains, and concludes "*that a Tertiary flora was contemporaneous with a Cretaceous fauna, establishing an uninterrupted succession of life* across what is generally regarded as one of the greatest breaks in geologic time." His further remark that "the appearance of mammalia and sudden disappearance of the large Mesozoic types of reptiles may be regarded as *evidence of migration and not of creation*," embodies a thought that has been since revived and extended.

To this report of Professor Cope, as published in the Annual Report for 1873, he appends a short discussion, not contained in the Bulletin, in the nature of a reply to the article of Dr. Newberry above referred to. In the course of this discussion the following remarks occur: "If a flora below the Cretaceous of New Mexico resembles a Tertiary one, how much more probable is it that the floras of the Lignites of Colorado and Wyoming are such, as they are known to be of later age than those of New Mexico, and to be at the summit of the Cretaceous series, as indicated by animal remains; and if the flora of the Fort Union beds be Miocene, that of the identical horizon in Colorado must be Miocene also; and if the vegetation below this flora be so distinct from it, what is more probable, according to the evidence adduced by Dr. Newberry, than that they are Eocene, as maintained by Mr. Lesquereux? That such should be the case is in harmony rather than in conflict with the facts presented by the existing life of the earth, where we have the modern fauna of the northern hemisphere contemporary with a partly Eocene and partly Mesozoic fauna in the southern."

The same volume contains a report by Mr. Archibald Marvine of his operations during the season of 1873 in the park districts of Colorado. In treating the "Lignitic formation," as observed by him, he reviews the evidence from the plant remains, as interpreted by Lesquereux, as well as that furnished by vertebrate life, and says: "It must be supposed, then, that either a Cretaceous fauna extended forward into the

Eocene period, and existed contemporaneously with an Eocene flora, or else that a flora wonderfully prophetic of Eocene times anticipated its age and flourished in the Cretaceous period to the exclusion of all Cretaceous plant forms. * * * In either case, the fact remains that here the physical and other conditions were such that one of the great kingdoms of life, in its progress of development, either lost or gained upon the other, thus destroying relations and associations which existed between them in those regions from which were derived the first ideas of the life boundaries of geological time, causing here apparent anomalies." He adds the following important paragraph: "Much of the confusion and discrepancy has, in my opinion, arisen from regarding different horizons as one and the same thing. It must be distinctly understood that this group as it exists east of the mountains in Colorado is very different from, and must not be confounded with, the horizon in which much of the Utah and New Mexican lignite occurs, and which belongs undoubtedly to the Lower Cretaceous; and, further, that the extended explorations of Hayden and others would seem to prove almost conclusively that the Colorado lignitic group is the direct southern stratigraphical equivalent of the Fort Union group of the Upper Missouri, which is considered generally to be no older than the Eocene, while Newberry asserts it to be Miocene."

Mr. Lesquereux returns again, in his contribution to this same volume, to the defense of his former position. He disposes in a manner of the statement that characteristic Cretaceous molluscan fossils had been found "above the beds of the lignitic formations" by quoting Messrs. Cox and Berthoud, the collectors of the specimens about which so much had been said, who both show that the conditions under which they occurred were such as to render their stratigraphical position too doubtful to form the basis for such important generalizations. He reasserts his belief in "the unity of the Lignitic formation in its whole," and reargues the whole case. He also revises his "groups" and gives lists of all the species found in each.

In Volume VII of the Canadian Naturalist, p. 241, published in 1874, Mr. George M. Dawson discusses "The Lignite Formations of the West," now discovered to extend far up into Canadian territory. He regards them as of later age than the Cretaceous and accepts the view of Messrs. Hayden and Lesquereux that the Fort Union group is Eocene. Referring to the opinions of Cope, he says: "The evidence does not appear to show that the Cretaceous species were of themselves becoming rapidly extinct, but that over the Western region, now forming part of this continent, the physical conditions changing drove the Cretaceous marine animals to other regions, and it is impossible at present to tell how long they may have endured in oceanic areas in other parts of the world. This being so, and in view of the evidence of the preponderant animal and vegetable forms, it seems reasonable to take the well marked base of the Lignite series as that of the lowest Tertiary, at least at present. The formation described belongs to this lowest Tertiary, being, in fact, an extension of Hayden's *Fort Union group,* and from analogy may be called *Eocene.*"

In a more formal paper[1] published the same year, he also says: "The formation is, however, undoubtedly an extension of the Great Lignite or Fort Union group of strata of Hayden, as developed in the Western States and Territories. * * * These strata immediately succeeding the Cretaceous rocks are the lowest American representatives of the Tertiary series and have been called for this reason Eocene, though it is impossible to affirm that their deposit was more than approximately synchronous with that of the Eocene as constituted in Europe" (p. 20).

Returning to the same subject a year later in his final report of the Northwest Boundary Commission,[2] after familiarizing himself with the discussions going on in the United States, the same author adheres to his previous views and remarks: "There seems little doubt, however, that the general tenor of the evidence of these beds, when considered alone, favors their Lower Eocene age. Their exact synchronism with the European Eocene is a question apart from the present inquiry" (p. 186).

Early in 1875 Professor Cope, who had examined the vertebrate remains sent him by Mr. Dawson from near Milk River, on the boundary of the British possessions, published a note upon them,[3] in which he says: "The genus of tortoises *Compsemys,* Leidy, is peculiar to the Fort Union epoch, while *Plastomenus,* Cope, belongs to the Eocene. Its presence in this fauna would constitute an important assimilation to the Lower Tertiary, but the specimens are not complete in some points necessary to a final reference. The species are in any case nearly allied to that genus. There are, however, gar scales included in the collection which closely resemble those of the genus *Clastes* of the lower Eocenes of the Rocky Mountains. This is empirically another indication of near connection with Tertiary time, but not conclusive, since allied genera have a much earlier origin in Mesozoic time. * * * Nevertheless, the list of species, short as it is, indicates the future discovery of a complete transition from Cretaceous to Eocene life more clearly than any collection yet obtained marking this horizon in the West."

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[1] Report on the Tertiary Lignite Formation in the Vicinity of the forty-ninth parallel. By George M. Dawson. Addressed to Capt. D. R. Cameron, R. A., H. M. Boundary Commissioner. British North American Boundary Commission. Geological Report of Progress for the year 1873 [in part]. Montreal, 1874.

[2] British North American Boundary Commission. Report on the Geology and Resources of the Region in the Vicinity of the forty-ninth parallel, from the Lake of the Woods to the Rocky Mountains, with lists of plants and animals collected, and notes on the fossils. By George Mercer Dawson, geologist and botanist to the Commission. Addressed to Maj. D. R. Cameron, R. A., H. M. Boundary Commissioner. Montreal, 1875.

[3] Proceedings of the Academy of Natural Sciences, Philadelphia, Jan. 5, 1875, Vol. XXVII, pp. 9, 10.

Professor Cope's article, from which we made quotations a few pages back, appeared for the third time in his final report on fossil vertebrates[1] with very few changes. It is to be noted, however, that he no longer proposes to call the lignite deposit the sixth member of the Cretaceous formation of the West, and referring to the fossils from the Milk River district last mentioned we find him saying "that there are present two genera in this collection which are diagnostic of the Fort Union epoch, but no species certainly so, though two species are probably identical with species of that epoch; also * * * that the species referred to *Plastomenus* constitute an indication of affinity with corresponding Eocene forms. The presence of gar fishes of the genus *Clastes* in this formation is as yet peculiar to this and the Judith River localities. As these gars have not heretofore been found in North America below the Eocene, they constitute the first case of apparent commingling of Tertiary and Cretaceous animal life yet clearly determined." He is careful to add, however, that the evidence of the Dinosaurs outweighs these considerations.

At this time, when at least one vertebrate paleontologist was beginning to concede that this formation, though apparently Mesozoic, yet possessed a marked Tertiary facies, Mr. John J. Stevenson came forward with several papers[2] from the stratigraphical side in support of the Cretaceous theory. His language is the most positive of any yet employed, but a careful examination of his statements shows that his argument acquired its chief force from the form in which it was put forward. Such statements as that "everywhere the sandstones of the Upper Cretaceous present the same lithological character;" that "not a single Tertiary species occurs in the whole series;" that "wherever animal remains occur with this fucoid [Halymenites] they are invariably characteristic Cretaceous species;" that "the evidence in favor of Cretaceous age is abundant;" that the record of plant life is "little better than a blank, with here and there a few markings, many of which are too indistinct to be deciphered;" that "the only fossils characteristic of No. 5 ever obtained from Colorado were procured from rocks which are most probably the very highest strata of the Lignitic series"—would, if the question were at all one of credibility, as it is not, clearly invalidate this witness and make his own charge, "*falsus in uno, falsus in omnibus*," peculiarly applicable to himself. Mr. Stevenson's writings, however, have the merit of defending the essential unity of all the lignitic deposits.

[1] Report of the United States Geological Survey of the Territories, Vol. II, 4°, 1875, pp. 25–41.

[2] Proceedings of the Society of Natural History, New York, 2d ser., No. 4, 1874, p. 93; Age of the Colorado Lignites, Reports upon Geographical and Geological Exploration and Survey West of the One Hundredth Meridian, in charge of First Lieut. Geo. M. Wheeler, Vol. III, 1875, pp. 404–410; The Geological Relations of the Lignitic Groups, Proceedings of the American Philosophical Society, Vol. XIV, pp. 447–475.

The Annual Report of the Geological Survey of the Territories under Dr. Hayden for 1874, published in 1876, contains three very important papers upon this subject. The first is by Dr. Hayden himself, who labors effectively to "connect the coal-bearing beds of the Laramie Plains and Colorado with the vast group in the Northwest," but concedes the Cretaceous age of the Bear River and Coalville deposits. He says that "above the upper Fox Hills group there are about 200 feet of barren beds which may be regarded as beds of passage to the Lignitic group, which more properly belong with the Fox Hills group below. In this group of transition beds all trace of the abundant invertebrate life of the great Cretaceous series below has disappeared. * * * Whatever view we may take with regard to the age of the Lignitic group, we may certainly claim that it forms one of the time boundaries in the geological history of our western continent. It may matter little whether we call it Upper Cretaceous or Lower Eocene, so far as the final result is concerned. * * * Even the vertebrate paleontologists, who pronounce with great positiveness the Cretaceous age of the Lignitic group, do not claim that a single species of vertebrate animal passes above the horizon I have defined from the well marked Cretaceous group below."

The second of these papers is by Dr. A. C. Peale, who has here performed good service in preparing tables to illustrate the progress of opinion on this subject. In addition to this, however, after stating the character of his own investigations, he gives it as his opinion that "the lignite-bearing beds east of the mountains in Colorado are the equivalent of the Fort Union group of the Upper Missouri, and are Eocene-Tertiary; also, that the lower part of the group, at least at the locality two hundred miles east of the mountains, is the equivalent of a part of the lignitic strata of Wyoming;" but he thinks that "the Judith River beds have their equivalent along the eastern edge of the mountains, below the Lignite or Fort Union group, and also in Wyoming, and are Cretaceous, although of a higher horizon than the coal-bearing strata of Coalville and Bear River, Utah. They form either the upper part of the Fox Hills group (No. 5) or a group to be called No. 6."

Finally we have another exhaustive paper by Mr. Lesquereux, in which he divides the arguments against the Tertiary theory into five propositions and answers each in detail. Important discoveries of fossil plants had been made during the year at Point of Rocks, and these are made to lend their weight to his argument. It is needless to say that his conclusions remained unchanged.

The ninth volume of the final quarto reports of the Geological Survey of the Territories, consisting of Mr. Meek's report on the invertebrate Cretaceous and Tertiary fossils of the Upper Missouri country, appeared in 1876. In this report Mr. Meek takes the ground that the Judith River beds are distinct from the Fort Union group proper and of Cretaceous age, or at least probably so; but he is inclined to believe, from the occurrence of similar forms in both, that they are the equivalent of the Bitter Creek series in Wyoming. As to the Fort Union beds, he adheres to his former opinion, that they represent the lower Eocene. He deprecates the attempt to unify all the lignite-bearing rocks, and remarks: "The presence or absence of lignite proves nothing of itself, as lignite undoubtedly occurs in both Cretaceous and Tertiary rocks in the far West." In his comparisons of the Fort Union with the Wyoming deposits he states that the species of the former are all different from those of the Bitter Creek group, and concludes that these groups at least cannot be equivalents. Mr. Meek's concluding remarks upon the conflicting testimony of fossils and its lessons (pp. lx, lxi) are a model of scientific reasoning, and doubtless went far to mitigate the acerbity of this prolonged debate.

Powell's Geology of the Uintah Mountains was published the same year (1876) as the report last mentioned, and contains an important contribution to the present subject. Professor Powell and Dr. C. A. White had gone carefully over the disputed ground of the Bitter Creek district, tracing it up to its junction with the Washakie and Green River beds on the west, and in this volume both these authorities record their conclusions, which are in substantial accord. The former remarks (p. 67): "The relation of these groups to those established by Professors Meek and Hayden on the Upper Missouri is not well determined. * * * All the evidence that has been published by Dr. Hayden and members of his corps concerning the Park Province, and all my own observations in that region, lead me to the conclusion that a long chain of islands stretched in a northerly and southerly direction through that region of country, separating the Cretaceous sea of the Plateau Province from the Cretaceous sea of the Upper Missouri."

Between Black Buttes Station and Point of Rocks Station, on the Union Pacific Railroad, these gentlemen discovered a "physical break" in the series, exposing at the latter point a lower formation; and at this point they fixed the line between Mesozoic and Cenozoic strata, assigning, in the table of groups on page 40, the Point of Rocks group to the Cretaceous and the Bitter Creek group to the Tertiary. On this subject Professor Powell says (p. 71): "On account of the discussions which have arisen concerning the age of certain beds of lignitic coal, the plane of demarkation between the Cenozoic and Mesozoic may subject me to criticism; but, geologically, the plane is important, as it represents a decided physical change, and it certainly harmonizes with the opinion of paleontologists to a degree that is somewhat surprising. All of the plants described by Professor Lesquereux and collected by himself and others within this province have been referred by him to divisions in the Tertiary, and are found in strata above this physical break, and hence I agree with him in considering them Tertiary. * * * The conclusions reached from a study of the vertebrate paleontology by Professors Leidy, Marsh, and Cope entirely harmonize with this division of the Cenozoic and Mesozoic. There is a single exception to this: Professor

Cope described a *Dinosaur* found near Black Buttes Station as Cretaceous. I have verified the determination of the stratigraphic horizon by examining the place and finding other *Dinosaur* bones; but this horizon is above the physical break, and the evidence of the *Dinosaur* seems to be contradicted by the evidence furnished by many other species described by Professor Cope from about the same horizon."

Dr. White also discusses this question in the same volume, and states his reasons for regarding the Point of Rocks beds as Cretaceous in the following words (pp. 83, 84): "There is no physical break between this group and the Salt Wells group below it. Its strata contain at least three species of Inoceramus, which genus has never been known in strata of later date than the Cretaceous period. Odontobasis, a species of which has been obtained from near the summit of the group, is regarded as a Cretaceous genus; and in view of the facts before stated, that land and fresh- and brackish-water mollusks are comparatively valueless as indices of the passage of geological time, the presence of no known forms in its strata forbids the reference of this group to the Cretaceous period."

On the other hand, the Bitter Creek series proper is referred to the Eocene, and to the question "Why has the dividing line between the strata of the Tertiary and Cretaceous periods been drawn where it is rather than at some horizon either above or below it?" his answer is: "There is no physical break in the Cretaceous strata from the base of the series to the top of the upper, or Point of Rocks group, at which horizon there is at all observed points, extending over a large region, a considerable unconformability by erosion of the lower strata of the Bitter Creek group upon the upper strata of the Point of Rocks group (p. 87)."

The second volume of the Reports of the Geological Exploration of the Fortieth Parallel by Mr. Clarence King, which appeared in 1877, contains exhaustive papers upon the geology of this region by Messrs. Arnold Hague and S. F. Emmons, who had studied the rocks with great care. Both these gentlemen agree in referring the entire lignite-bearing series to the Cretaceous. They do not draw the nice distinction made by Messrs. King, Powell, and White, but Mr. Hague seems to have no doubt that even the Carbon coals belong there, while Mr. Emmons similarly disposes of those of Evanston. In this report the term *Lignitic* is abandoned altogether and the term *Laramie* is applied to this formation. Mr. Emmons constantly speaks of the "Laramie Cretaceous" and the "Laramie group," the latter of which terms has now been generally adopted and extended over a much wider area.

In his vice-presidential address, delivered before the American Association for the Advancement of Science, at Nashville, Tenn., August 30, 1877, Prof. O. C. Marsh expressed himself as follows upon the general subject under discussion: "The boundary line between the Cretaceous and Tertiary in the region of the Rocky Mountains has been much in dispute during the last few years, mainly in consequence of the uncertain geological bearings of the fossil plants found near this horizon. The accompanying invertebrate fossils have thrown little light on the question, which is essentially, whether the great lignite series of the West is uppermost Cretaceous or lowest Eocene. The evidence of the numerous vertebrate remains is, in my judgment, decisive, and in favor of the former view."[1]

At about this time the researches of Dr. C. A. White, who had become deeply interested in this formation, began to bring forth important results. His "Paleontological Papers" commenced to appear in 1877, as contributions to the Bulletins of Dr. Hayden's Survey, in the third of which he drew up tables of the groups of the Green River and Upper Missouri River regions. It was here that he employed the term "Post-Cretaceous," to include the Laramie group of the King Reports and the lower third of the Wasatch group, and correlating the Judith River with the Laramie and the Fort Union with the Wasatch group. In the fifth of these papers, published the same year, he enters more fully into the discussion of the age of these groups and remarks: "With a few doubtful exceptions, none of the strata of the Laramie group were deposited in open sea waters; and, with equally few exceptions, none have yet furnished invertebrate fossils that indicate the Cretaceous rather than the Tertiary age of the group. These latter exceptions are some *Inocerami* that have been obtained upon the lower confines of the group, and doubtfully referred to it rather than to the Fox Hills group below; and also a species of *Odontobasis* from strata near the top of the group, two miles west of Point of Rocks Station, Wyoming. The latter genus, established by Mr. Meek, is comparatively little known, but it was regarded by him as characteristic of the Cretaceous period. This constitutes the slender evidence of the Cretaceous age of the Laramie group that invertebrate paleontology has yet afforded.

"Again, the brackish- and fresh-water types of *Mollusca* that are afforded by the Laramie and the lower portion of the Wahsatch group are in most cases remarkably similar, and some of the species of each group respectively approach each other so nearly in their characteristics that it is often difficult to say in what respect they materially differ. Moreover, they give the same uncertain indication as to their geological age that all fossils of fresh- and brackish-water origin are known to do.

"It is in view of the facts here stated, and also because I believe that a proper interpretation of them shows the strata of the Laramie group and the base of the Wahsatch to be of later date than any others that have hitherto been referred to the Cretaceous period, and also earlier

[1] Proceedings of the American Association for the Advancement of Science, 1877, page 229.

than the Eocene epoch, that I have decided to designate those strata as Post-Cretaceous, at least provisionally."

By a remarkable coincidence this term *Post-Cretaceous* was applied to the lignitic beds of the Trinidad district, New Mexico, by Dr. F. M. Endlich, in the Annual Report of the Geological Survey of the Territories for 1875 (p. 206), published in 1877; but it is impossible to say which of these reports should have priority, and as the term has now been generally abandoned this is quite unimportant.

In the death of Mr. F. B. Meek the science of invertebrate paleontology lost one of its ablest votaries, and but for the fact that Dr. C. A. White had already entered the field in this rôle as well as in that of stratigraphical geologist, this department of research in our western formations might have been sadly neglected. But the now rapidly increasing writings of the latter author fully supplied the place of the former, and the contest went on. In the Annual Report of Dr. Hayden's Survey for 1876, published in 1878, Dr. White reports his operations during the years 1876 and 1877 in Colorado, in which paper he takes occasion to draw up a section of the rocks and to prepare a table of correlated general sections which are highly instructive. Confining ourselves to the Laramie group, we see that he adopts that term and makes it commensurate with his Post-Cretaceous, to which he still adheres, and also with the Laramie of King and the Lignitic of Meek and Hayden. The Point of Rocks group of Powell begins with the Laramie, but stops at a lower horizon, his Bitter Creek group occupying the remainder, and the whole of the Wasatch (the Vermilion Creek group of King). In defense of his course in receding from his former position, in which his views agreed with those of Powell, he says: "After a careful examination of the extensive exposures of this series of strata, as well as those of the Wasatch group above it in this district, I have failed to discover any unconformity such as exists in the valley of Bitter Creek. Therefore, the greatest unconformity that is now known to exist among any of the strata from the base of the Cretaceous to the top of what I here designate as the Post-Cretaceous, is found among the strata of the latter group, and not at its top. In this district and the region immediately adjoining it, whatever catastrophal or secular changes may have meanwhile taken place elsewhere, or even extending within its limits, sedimentation was evidently continuous and unbroken, not only through this series itself, but also into and through the whole Wasatch group.

"The fact that this series passes insensibly into the Fox Hills group below, and into the Wasatch group above, renders it difficult to fix upon a stratigraphical plane of demarkation, either for its base or summit. I have, therefore, decided to regard this group as essentially a brackish-water one, referring all strata below that contain any marine Cretaceous invertebrate forms to the Fox Hills group, beginning this series with those strata that contain brackish- and fresh-water forms, and ending it above with those strata in which the brackish-water forms finally cease. Thus defined, the whole series seems to form one natural paleontological group, as well as to be a sufficiently distinct stratigraphical one, for which I have adopted the name of Laramie group of King."

In giving his reasons for adhering to the name Post-Cretaceous, Dr. White further says: "The flora of this group is understood to be wholly of Tertiary types, according to Professor Lesquereux. None of its invertebrate fossils are of distinctive Cretaceous types, although fossils of similar types are known to occur in Cretaceous as well as Tertiary strata. So far, then, as the flora and invertebrate fauna are concerned, there is nothing to indicate the Cretaceous age of the group. In fact, invertebrate paleontology is utterly silent upon the subject. On the contrary, Professor Cope finds reptilian remains, even in the uppermost strata of the group, that he regards as of Cretaceous type. I believe that, upon the evidence of invertebrate paleontology, the Fox Hills group is later than the latest Cretaceous strata of Europe; and I therefore regard the Laramie group as occupying transitional ground between the well marked Cretaceous and Tertiary groups, but this opinion is only tentatively held until further facts are obtained."

The term *Post-Cretaceous* is employed by both Endlich and Peale in their reports in this volume (pp. 77, 109, 181).

In his seventh Paleontological Paper (Bulletin U. S. Geological Survey of the Territories, Vol. IV, No. 3), distributed in 1878, Dr. White greatly extends the boundaries of the Laramie group, making it embrace "both the Judith River and Fort Union series of the Upper Missouri River; the Lignitic series east of the Rocky Mountains in Colorado; the Bitter Creek series of Southern Wyoming and the adjacent parts of Colorado; and also the 'Bear River estuary beds,' together with the Evanston coal series of the valley of Bear River and adjacent parts of Utah," as well as strata known to exist in other large and widely separated districts of the western portion of the National domain, and he gives a list of species characteristic of the group, showing their distribution throughout these several districts.

Mr. Leo Lesquereux's so-called "Tertiary Flora" constitutes the seventh volume of the final reports of the Geological Survey of the Territories under Dr. F. V. Hayden, which, of course, embraces the plants of the Laramie group. In it Mr. Lesquereux has given full scope to the expression of his views upon the age of this group, and it is naturally here that we must look for the most able and exhaustive treatment of the subject thus far presented by this author. In the letter of Dr. Hayden to the Secretary of the Interior transmitting this report, and which bears date January 1, 1878, he again reviews this subject and remarks: "The author states that his final conclusions do not differ materially from those already advanced by myself, and he regards the evidence as conclusive that the Lignitic group is of Tertiary age. This result is gratifying, not only as settling the question at issue, but as silencing criticism of the value and reliability of the general work accomplished by the survey under my direction." But in this same letter Dr. Hayden also declares his conviction, more than once before expressed, but not as yet, so far as I know, accepted by either Lesquereux or Newberry, "that the Fort Union beds of the Upper Missouri River are the equivalent of the Lignitic formation as it exists along the base of the Rocky Mountains, in Colorado," as well as of the Bitter Creek series west of the Rocky Mountains, as argued by Dr. White, and he says: "It is also probable that the brackish-water beds on the Upper Missouri must be correlated with the Laramie, and that the Wahsatch group as now defined and the Fort Union group are identical as a whole, or in part at least."

As Mr. Lesquereux's conclusions expressed in this report are the same as he had held throughout the discussion, and the arguments not new, no further elucidation of them is necessary.

Volume I of Mr. Clarence King's Geological Reports of the Survey of the Fortieth Parallel, treating of the systematic geology, and written by Mr. King himself, did not appear until 1878. His views upon this question were looked for with great interest, though it was, of course, to be expected that they would coincide generally with those of his assistants already published in other volumes. Notwithstanding the tendency, which had been marked for several years, to regard the attempt to assign the Laramie group to either the Cretaceous or Tertiary age as not only profitless but rather puerile, inasmuch as its relative position in the western American system was so well settled, Mr. King did not consider it beneath the dignity of this stately report to approach the subject much from the old standpoint and record his position in nearly conventional terms. He says (p. 350): "Aside from the Taconic system, no single geological feature in all America has ever given rise to a more extended controversy than the true assignment of the age of this group. On data which will presently be set forth, it is assumed by us to be the closing member of the Cretaceous series, and the last group of the great conformable system which east of the Wahsatch stretches upward from the base of the Cambrian."

The views that had been put forth in opposition to this he then arranges into a series of seven "assumptions," which he proceeds to consider and dispose of in the order laid down. As some of these points are admitted and others not vital, they need not be noticed *seriatim;* a few extracts must suffice. He says (p. 352): "A complete refutation of assumption three, that the fauna proves a Tertiary, not a Cretaceous age, is found in the fact that the evidence of a meagre molluscan life and a large range of plants cannot be held to weigh against the actual presence of *Dinosauria* in the very uppermost Laramie beds, and, as will appear in the sequel, of an abundant *lowest Eocene* mammalian fauna in the unconformably overlying Vermilion Creek group. * * * Assumption number five, as to the conformity of the Laramie with the Wahsatch group, I shall presently proceed to show, is based upon imperfect knowledge, and is abundantly disproved by repeated sections."

Relative to the Fort Union group, he admits that he had never visited that locality, but notes the conflicting evidence of vertebrate and vegetable remains, and Mr. Lesquereux's silence upon the latter in his Tertiary Flora, and remarks (p. 353) that "the further correlation of the upper plant-beds of Fort Union with the Wahsatch (my Vermilion Creek) seems the most prodigious strain. The Wahsatch (Vermilion Creek), or unmistakable lowest Eocene, is nonconformable with the Laramie. The relations of conformity or nonconformity between the plant-bearing beds of Fort Union and the Dinosaurian beds are not given, and there is reason to believe that the plant beds represent a horizon of the great White River Miocene series, which underlies the Pliocene over so large a part of the Great Plains. * * * I apprehend that the plant horizon at Fort Union will be found to be nothing but the northward extension of the White River Miocene."

Professor Cope's paper on horizons of extinct vertebrata, in the fifth volume of the Bulletins of the United States Geological and Geographical Survey of the Territories (No. I, Art. II), which appeared early in the year 1879, is of special value as the first attempt to correlate the Laramie group with European strata upon the evidence of vertebrate remains. This discussion was repeated without essential change in his great work which forms Book I of the third volume of the final quarto reports of that Survey, published in 1884. The general result is a still further yielding on the part of the writer to the views of the invertebrate and vegetable paleontologists against the decidedly Cretaceous character of the group. He shows in an instructive way that it bears a very close relation to the Sables of Bracheux and Conglomerates of Cerny, which are Eocene, but with this difference, "that the characteristic genera of reptiles and fishes of the Laramie of North America are in America associated with Cretaceous *Dinosauria* and not with *Mammalia*; while in Europe they are associated with *Mammalia* and not with *Dinosauria*." And he adds: "In arranging the Laramie group, its necessary position is between Tertiary and Cretaceous, but on the Cretaceous side of the boundary, if we retain those grand divisions, which it appears to me to be desirable to do;" and he admits "that another formation must be added to the series already recognized in France, viz, the Laramie, or Post-Cretaceous." This he does in his table of correlated general sections, on page 50, making the Post-Cretaceous embrace the Laramie and the Puerco, the former in turn being equivalent to the combined strata of the Judith River and Fort Union deposits.

Dr. C. A. White's elaborate report upon his extensive field researches made in 1877 appeared in the Annual Report of the Geological Survey of the Territories for that year, which, however, did not see the light till

1879. Dr. White had spent the entire season in the exhaustive study of the various outcrops of the Laramie in Colorado and Wyoming on both sides of the Rocky Mountains, and had made large and valuable collections, which he had worked up with care, and which form the substantial basis for his conclusions as here set forth. In his "general discussion," which follows the detailed report, starting with "the unity of all the principal brackish-water deposits hitherto known in the Western Territories, and * * * their recognition as a comprehensive group of strata under the name of the Laramie group, which represents a great period in geological time, and especially such in the geological history of North America," he proceeds to discuss, not so much the *age* of the group, as the conditions of its deposition and the geological history of the western part of the continent following the close of true Cretaceous time. Into this discussion, though confessing its superior importance, we cannot here enter, but must be content to cite a passage or two to show to what conclusions he had now come relative to the age of the Laramie group, its geographical boundaries, and the thickness of its deposits. He says:

"Resting directly upon the strata of the Fox Hills group are those of the Laramie group, the latter, as already shown, having been, at least in part, deposited continuously with the former. The geographical boundaries of the great Laramie formation are not known, but its area embraces many thousand square miles, for it is known to extend from Southern Colorado and Utah northward beyond the northern boundary of the United States, and from the Wahsatch Mountains eastward far out on the great plains. It reaches a maximum thickness of about 4,000 feet, and its general lithological characteristics are similar to those of the Fox Hills group, a known marine formation. Its fauna, however, has been shown to be largely of brackish- and partly of fresh-water origin, and not marine. Furthermore, the brackish-water species are distributed throughout its entire thickness and its whole geographical extent. These facts, together with the absence from all the strata yet examined of any true estuary characters, show that the Laramie group was deposited in a great brackish-water sea. * * *

"In the foregoing report I have purposely avoided an expression of opinion as to the true geological age of the Laramie group, because, notwithstanding the positive opinions that have been expressed by others upon that subject, I regard it as still an open question. * * * The claim that Cretaceous types of vertebrates are found in even the higher strata of the Laramie group is freely conceded, and I have no occasion to question the reference that has been made of its fossil plants, even those of the lowest strata, to Tertiary types. The invertebrate fossils of the group itself, as I have elsewhere shown, are silent upon this subject, because the types are either unique, are known to exist in both Mesozoic and Tertiary strata, or pertain to living as well as fossil forms. Every species found in the Laramie group is no doubt extinct, but the types have collectively an aspect so modern, that one almost instinctively regards them as Tertiary; and yet some of these types are now known to have existed in the Cretaceous and even in the Jurassic period.

"In view of the conflicting and silent character, respectively, of these paleontological oracles the following suggestions are offered: It is a well-known fact that we have in North America no strata which are, according to European standards, equivalent with the Lower Cretaceous of Europe, but that all North American strata of the Cretaceous period are equivalent with those of the Upper Cretaceous of that part of the world. That the Fox Hills group is of Upper Cretaceous age no one disputes, the only question being as to its place in the series. A comparison of its fossil invertebrate types with those of the European Cretaceous indicates that it is at least as late as, if not later than, the latest known Cretaceous strata in Europe. If, therefore, that parallelism is correctly drawn, and the Laramie group is of Cretaceous age, we have represented in America a great and important period of that age which is yet unknown in any other part of the world. Besides this, we may reasonably conclude that the Fox Hills group of the West is equivalent with the Upper Cretaceous strata of the Atlantic and Gulf coasts, between which and the Eocene Tertiary of those regions there is no known equivalent of the Laramie group.

"If paleontologists should finally agree upon regarding the Laramie group as of Cretaceous age, it must be because of the continuance of certain vertebrate Cretaceous types to the close of that period, and the presence of mammalian Tertiary types in the strata immediately following; but the following facts, in addition to those which have been already stated, should be carefully considered before any such agreement is made:

"With rare and obscure exceptions no mammalian remains are known in North American strata of earlier date than that of those which were deposited immediately after the close of the Laramie period and upon its strata. Immediately from and after the close of the Laramie period their abundant remains in the fresh-water Tertiaries of the West show that highly-organized mammals existed in great variety and abundance; all of which may be properly regarded as constituents of a Tertiary fauna, and many of which are by accepted standards of distinctively Tertiary types. If the presence of these forms in the strata referred to, and their absence from the Laramie strata immediately beneath them, together with the presence of Dinosaurians there, be held to prove the Tertiary age of the former strata, then was the Tertiary period ushered in with most unnatural suddenness. Sedimentation was, at least in part, unbroken between the Laramie group and the strata which contain the mammalian remains referred to, so that the local conditions of the origin of all of them were substantially the same, and yet, so far as any accumulated evidence shows, those mammalia were not preceded in the Laramie period by any related forms. Such suddenness of introduction makes it almost certain that it was caused by the removal of some physical barrier, so that ground which was before potentially Tertiary became so by actual faunal occupancy. In other words, it seems certain that those Tertiary mammalian types were evolved in some other region before the close of the Laramie period, where they existed contemporaneously with at least the later Laramie Dinosaurians of Cretaceous types, and that the barrier which separated the faunæ was removed by some one of the various movements connected with the evolution of the continent. The climate and other physical conditions which were essential to the existence of the Dinosaurians of the Laramie period having evidently been continued into the Tertiary epochs that are represented by the Wahsatch, Green River, and Bridger groups, they might doubtless have continued their existence through those epochs as well as through the Laramie period, but for the irruption of the mammalian horde, to which they probably soon succumbed in an unequal struggle for existence."

From the above extracts it will at once be seen that Dr. White had now succeeded in raising this discussion from the comparatively trivial question as to the name which should be given to the age occupied by the Laramie group to one involving not only the manner in which the continent was formed, but also the origin, development, extinction, and succession of the different forms of life which have left in the rocks a trace of their former presence as constituting its inhabitants. The considerations last urged have an especial interest from the point of view of vegetable paleontology, which presents a close parallel, though at a considerably lower horizon.

In the next annual report Dr. White goes over the same ground and sets forth his views anew, supported by fresh facts. In fixing the boundaries of the Laramie sea, he says (p. 49): "The geographical limits of the Laramie group are not yet fully known, but strata bearing its characteristic invertebrate fossils have been found at various localities within a great area, whose northern limit is within the British Possessions and whose southern limit is not further north than Southern Utah and Northern New Mexico. Its western limit, so far as known, may be stated as approximately upon the meridian of the Wahsatch range of mountains, but extending as far to the southwestward as the southwest corner of Utah, and its eastern limit is far out on the great plains, east of the Rocky Mountains, where it is covered from view by late formations and the prevailing *débris* of the plains. These limits indicate for the ancient Laramie sea a length of about one thousand miles north and south, and a maximum width of not less than five hundred miles. Its real dimensions were no doubt greater than those here indicated, especially its length; and we may safely assume that this great brackish-water sea had an area of not less than fifty thousand square miles."

He reiterates his statement that "With the exception of one species of *Axinæa*, one of *Nuculana*, and one or two of *Odontobasis*, no species usually regarded as of marine types have been found in any of the strata of the Laramie group," and pronounces all statements in conflict with this, even though made by himself, as the result of errors in stratigraphical determination. He also repeats the remark (p. 51) that "among all the invertebrate fossils which have yet been discovered in the strata of the Laramie group, none of the types are distinctively characteristic of the Cretaceous period according to any hitherto recognized standard," and he adduces a mass of facts in support of the view previously advocated, "that the Laramie is really a transitional group between the Cretaceous beneath and the Tertiary above (p. 52)."

In the sixth volume of Prof. Oswald Heer's great work on the Arctic fossil flora,[1] the eminent Swiss paleontologist approaches this question of the age of the American plant-bearing beds. As might be expected, he strongly defends Mr. Lesquereux's position as to the Eocene age of the Laramie group against the arguments of those who would refer it to the Cretaceous. He characterizes the doctrine that the Dinosaurs became extinct at the close of the Mesozoic as a "dogma," and, speaking of Cope's *Agathaumas*, says that it by no means proves that a Tertiary flora was contemporary with a Cretaceous fauna, "for a single animal does not make a fauna any more than one plant makes a flóra," and instances the animal forms also found by Cope and others at the same horizon, which agree better with the Eocene faunas of France.

In the supplement to the third volume of the reports of Lieutenant Wheeler's Survey, which bears date 1881, Mr. John J. Stevenson again discusses the age of the Laramie group, adhering as warmly as ever to his previous views. As in his former reports, notwithstanding frequent denials in the meantime, he still insists (p. 154) that "farther north in Colorado characteristic Fox Hills fossils were obtained in abundance near the *summit of the fully recognized Laramie*." This and the further statement (p. 154) that "the fauna is either marine or brackish-water" are both contrary to the definition of the Laramie group as laid down by Dr. White, and indicate that this geologist had been unable to distinguish the marine from the brackish-water strata. In his final conclusion that the Laramie merely constitutes the upper part of the Fox Hills group (p. 158), Mr. Stevenson seems to be sustained by no other authority, even the stratigraphical geologists, fully aware of the conformity of the deposition, not being willing to regard a marine and a brackish-water deposit as a single homogeneous group.

The Third Annual Report of the United States Geological Survey, published in 1883, contains Dr. White's "Review of the non-marine fossil mollusca of North America," illustrated by 32 plates, 22 of which are devoted to species of the Laramie group, all of which are described

[1] Beiträge zur miocenen Flora von Nord-Canada. Zürich, 1880, pp. 6–10.

in the text, and which furnish a thorough and complete account of the invertebrate fauna of that group. In the "Introductory remarks" which precede and the "General discussion" that follows this "Annotated Catalogue," Dr. White again sets forth his views upon this great series of rocks, which, however, had undergone no change. Although he now drops the term *Post Cretaceous*, he still regards the Laramie group "as a transitional group between the Cretaceous and Tertiary series, and therefore as representing a period partaking of both the Mesozoic and Cenozoic ages." In defining the group anew, he says that "the 'Judith River group,' 'Fort Union group,' 'Lignitic group,' 'Bitter Creek coal series,' 'Point of Rocks group,' and 'Bear River estuary beds,' are all parts of the great Laramie group," but that "the 'Wahsatch group,' 'Vermilion Creek group,' and 'Bitter Creek group' are regarded as at least approximately equivalent strata, constituting the oldest member of the purely fresh-water Eocene Tertiary series of deposits in the West."

The most important part of this paper is the acute and suggestive geognostico biological discussion it contains respecting the origin and evolution of these brackish- and fresh-water invertebrate forms, but this is outside of our present limits, and need only be referred to.

The appearance of Prof. Archibald Geikie's new Text-Book of Geology, containing allusions to western American deposits, called forth from Dr. White a vigorous protest in his article on "Late Observations concerning the Molluscan Fauna, and the Geographical extent of the Laramie Group," in the American Journal of Science for March, 1883, in which he pronounces some of these statements erroneous, and says: "I do not hesitate to assert that not one of the molluscan species mentioned in that statement was ever found in strata of the Laramie group, the non-marine forms which he mentions being evidently those which were discovered by Mr. Meek in an estuary deposit of true Cretaceous age, at Coalville, Utah. Furthermore, not one of the numerous species which do characterize that group are anywhere mentioned in the book;" and, referring to Mr. Stevenson's writings, he says in the same article: "That any true Laramie strata ever alternate with those of the Fox Hills group, or any other marine Cretaceous group, or that any true marine fossils were ever collected from any strata of the Laramie group, I cannot admit. I regard all such statements as the result of a misunderstanding of the stratigraphical geology of the region in which such observations are said to have been made."

Having received a collection of typical Laramie fossils from the State of Nuevo Leon, Mexico, Dr. White is now able to extend the southern limit of the Laramie group to that point, and he states that the facts "show more and more clearly the integrity of the molluscan fauna of the great ancient intra-continental sea in which the Laramie group was deposited, and its separateness from the faunæ of all other North American groups of strata (op. cit., p. 209)."

The latest utterance of this protracted debate is that of Mr. Lesquereux, in his new work just issued from the press on the "Cretaceous and Tertiary Floras of the Western Territories."[1] He here consents, in harmony with the general tendency of the time, to drop the term Eocene from the title of this chapter and treat simply of the "Flora of the Laramie group," without, however, surrendering his conviction that that group belongs to Eocene time, which he reasserts, although he now admits that "the flora of the Laramie group has a relation, remarkably well defined, with that of Sézanne," to the east of Paris, where the plant bearing travertines of the Lac de Rilly yield, according to the Marquis Saporta, the oldest Tertiary flora yet discovered. He reviews the recently expressed views of White, Cope, and others, and seems quite well satisfied with the state of opinion at the date of writing with respect to the age of the Laramie group.

NATURE AND EXTENT OF THE LARAMIE GROUP.

In the foregoing review of opinion I have sought to illustrate the history of our knowledge of this remarkable formation of American rocks, and to show how, as that knowledge increased, the wide fluctuations which characterized the period of general ignorance and limited information gave way to a gradual convergence of views, an equilibration, as it were, of ideas, which is still going on and tending steadily toward the final settlement of opinion in harmony with all the facts.

I have given special prominence to the evidence furnished by animal remains and by stratigraphy, purposely leaving that from vegetable remains, generally consistent with itself, undiscussed, because they form the principal subject of this paper and can better be treated by themselves in a future place and in connection with other problems of greater real importance than that of their geological age.

One of the advantages of the historical method here employed is that it obviates the necessity of offering any special description of the group under consideration as introductory to the treatment of its flora, the reader being now much better prepared to understand such treatment than any preliminary explanations of my own could have rendered him.

He perceives, from what has been said, that the Laramie group is an extensive brackish-water deposit situated on both sides of the Rocky Mountains and extending from Mexico far into the British North American territory, having a breadth of hundreds of miles and representing some 4,000 feet thickness of strata. He can readily see that when this deposit was made an immense inland sea must have existed whose waters occupied the territory now covered by the Rocky Mountains. These waters were partially cut off from the ocean by intervening land areas, through which, however, one or more outlets existed communicating with the open sea at that time occupying the territory of

[1] Report of the United States Geological Survey of the Territories (Hayden), Vol. VIII, 1883, pp. 109-114.

the Lower Mississippi and Lower Rio Grande Valleys. That this great inland sea spread over this entire territory is not at all disproved by the absence of Laramie strata from large parts of it, since these parts are situated, in most cases, in mountainous regions where the upper strata might be expected to have been generally eroded away.

This Laramie sea existed during an immense period of time and was finally but very gradually drained by the elevation of its bed, through nearly the middle of which longitudinally the Rocky Mountains and Black Hills now run. The exceeding slowness of this event is shown by the fact, so clearly brought out by Dr. White, that the marine forms of the Fox Hills strata, as they gradually found themselves surrounded by a less and less saline medium on the rising of the intervening land area, had time to become transformed and adapted to brackish-water existence, while these new-formed brackish-water species, when the sea at length became a chain of fresh-water lakes, had time again to take on the characters necessary to fresh-water life.

Dr. White recognizes the fact that the upheaval of the strata that formed the bottom of this sea took place, not in one uniform process of elevation, but in a prolonged series of rhythmic fluctuations of level, whose algebraic sum constituted at length a mountain uplift. But the numerous coal seams one above another that characterize the greater part of these beds, and equally the successive deposits of vegetable remains at different horizons, speak even more eloquently than any animal remains can do of the oscillatory history of the bed of this sheet of water.

There may have been, and doubtless were, as Major Powell believed, many islands scattered over the surface of this sea in Laramie time, and the evidence generally warrants us in assuming that a low, level country surrounded the sea, with marshy and swampy tracts. The islands and shores were heavily wooded with timber that can be as certainly known in its general character as we can know the timber of our present forests. But that for the greater part of the Laramie period there also existed at no great distance a large amount of elevated land, there can be no doubt. The deposits are chiefly siliceous in the southern districts and argillaceous in the northern, but the nature of their deposition points unmistakably to the existence of large and turbulent rivers that fell into the quiet sea and brought down from areas of rapid erosion immense quantities of silt corresponding to the nature of the country over which they flowed in their course. Where these elevated sources of this abundant detritus were then located is one of the great problems for the present and the future geologist to work out.

The deposition of this material was almost always quiet, the particles suspended in the turbid waters of the streams silently settling from the buoyant waters of the sea as fast as they became distributed about the mouths of the rivers, and thus embedding the leaves that periodically fell in vast numbers into it. The marked absence of fruits, stems, and other objects that possess considerable thickness shows that this was the case, and also affords a rude index to the rate of deposition, since only such objects could be preserved as succeeded in being covered up. Thus by ascertaining the average rate of decay of vegetable substances and noting the objects of maximum thickness which are found preserved, the time necessary to form a deposit of that thickness becomes approximately known.

The discussions with regard to the age of the Laramie group which have been rapidly passed in review have, perhaps, sufficiently shown that it is impossible to refer that group either to the Cretaceous or to the Tertiary and in so doing harmonize all the facts that the group presents with those in conformity with which other deposits in other countries of the world have been so referred; but they have also sufficiently shown that this is not the fault of the investigators, but, so to speak, of the facts, and that the real disagreement is in the organic forms and the nature of the deposits, so that omniscience itself could never harmonize them with all kinds of forms and deposits in all parts of the world. It is, therefore, futile, and indeed puerile, longer to discuss this question, and we can well afford to dismiss it altogether and settle down to the more serious study of the real problems which still lie before us.

One of these problems is often confounded with the question of age, which should be rigidly distinguished from it. This is the question of synchronism. If it could be satisfactorily proved that the Laramie group was deposited at the same absolute time as the iron sands of Aix-la-Chapelle, the Credneria beds of Blankenburg, or the travertines of Sézanne, this would indeed be a great gain to science. But as the animal and vegetable remains cannot be made to agree, it seems hopeless to attempt to arrive at complete harmony in this respect. The most that can be profitably undertaken is to find two or more deposits widely separated geographically in which either the floras, the invertebrate faunas, or the vertebrate faunas substantially agree. With regard to the invertebrate faunas this seems hopeless so far as the Laramie group is concerned. If that group was deposited in the manner above described, it would be difficult to find another which owed its existence to identical conditions; and if this state of things has occurred at more than one point upon the globe, the chances are again greatly diminished for it to have occurred at the same period of geologic time. But even supposing such a combination of coincidences possible, if the Laramie forms are the modified descendants of antecedent marine forms, there is no probability that the conditions at any other point on the earth's surface could be so nearly identical with those obtaining there that precisely the same modifications would take place to adapt the marine forms to the brackish-water habitat. The chances are therefore infinity to one against the existence of other beds that shall contain an invertebrate fauna identical with that of the Laramie group.

It is therefore truly surprising to learn that "several of the species found in the brackish-water layers at the base of the Bitter Creek group are closely related to species found in similar deposits in Slavonia and referred to the Eocene Tertiary by Brusina."[1]

With regard to vertebrate remains, this objection does not apply, and could they be made to harmonize with themselves they might, perhaps, be trusted to some extent as indices of synchronism in widely separated localities. But, as shown by Cope, they do not thus agree, for the Laramie forms include genera that are regarded as characteristic of Cretaceous and others that are regarded as characteristic of Tertiary strata. This should surprise no one. The law that has been laid down by paleontologists, that the same epochs in geologic time produced the same living forms—which is the converse of the assumption commonly acted upon, that the occurrence of the same forms proves the beds containing them to be of the same age—is contrary to the now well established principles of geographical distribution, according to which the earth is subdivided into a large number of faunal areas more or less clearly marked off one from another. The peculiarity of this principle which is of most importance to paleontology is that these territorial subdivisions represent faunas not merely different from one another, but showing different degrees of biologic development as development is supposed to have gone on in the animal kingdom. Every one knows that the fauna of Australia belongs to an undeveloped type, being marsupial in aspect so far as its mammals are concerned. The types of South America are lower than those of North America, and the latter lower than those of Asia and Europe. If all the present faunas of the globe were buried under its soil it is clear that it would not only be impossible to harmonize the deposits of different continents, but that the inference now freely drawn by paleontologists that the less developed forms demonstrate their existence at earlier epochs would lead to grave mistakes and be generally false. New Zealand is now in its age of birds, while the Galapagos Islands are still in that of reptiles, or the Mesozoic age.

VEGETATION OF THE LARAMIE AGE.

Confining ourselves, then, for the future to the other kind of land life and the only remaining form of life, that of plants, we may look at the question of synchronism by the light of this class of data from the same general point of view as we have done by the light of the two kinds of animal life which we have just considered. And, first, what ought we to expect the flora of the Laramie group to teach respecting the synchronism of its deposits with those of other parts of the world? Clearly, as in the land vertebrate life, there is no special obstacle to this form of inquiry, such as the invertebrate aquatic life presents, arising

[1] Dr. White, in "Geology of the Uinta Mountains," p. 86.

out of the manner in which the Laramie sea was produced and the changing constituents of its waters. But all the other difficulties present themselves here as in the case last considered. While the vegetable remains seem to be more harmonious in pointing to a somewhat later period of time for their deposition than do those of vertebrate animals, the impropriety of inferring absolute synchronism from substantial agreement of forms is here even greater than in the other case. Taking the present flora of the globe as a criterion, we find that the geographical distribution of plants is more uneven than that of animals. Floral realms are more numerous and distinct than faunal realms, and the more serious obstacle that some areas furnish types representing less developed floras than others exists here as in the case of animals. The Proteaceous and Myrtaceous flora of Australia may be regarded as rudely corresponding to its marsupial fauna.

It is true that the paleontological doctrine of synchronism already stated is supported, as against the facts of geographical distribution, by the well established principle that older faunas and floras were characterized by less variety and greater uniformity of distribution over the earth's surface, which is verified in a remarkable manner by the well known uniformity of the flora of the Carboniferous epoch at all points where it has been discovered. And Baron Ettingshausen has shown that this principle continued in operation down to the close of the Tertiary age, though, of course, in a reduced degree, so that the present extraordinary variety in the floras of different countries must be largely attributed to the agency of the successive glacial epochs which have occurred since Tertiary time in driving the floras southward and out on the southern plains to be destroyed on the return of warmer climatic influences or compelled to intrench themselves upon the summits of the mountain ranges, while new and constantly varying forms became developed to take their places in the lowlands. Still, the uniformitarian law, that in its more general aspects the phenomena taking place on the earth in past geologic ages were the same as those which are still taking place, forbids us to assume that even as far back as Laramie time the same or any very similar flora occupied different hemispheres of the globe.

This much, however, can be said in favor of the flora of the Laramie group as affording data for the study of its deposits: that its remains occur far more abundantly than do those of any of the other forms of life. The low forest-clad shores and islands of the Laramie sea, which probably extended back at many points into extensive lagoons and vast swamps, were peculiarly adapted for receiving, as its muddy waters were for embedding, the various kinds of vegetable matter that found their way into them. The swamps formed extensive beds of peat, and vast marshes densely covered with cane, bamboo, and scouring rush left thick annual accumulations of vegetable matter which, at points of slow temporary subsidence, formed the coal beds. The plant beds which usually overlie these coal beds tell us that the rate of subsidence had now exceeded that of the growth of the deposit and the shallow sea had gained access, burying the last of the plants under its siliceous or argillaceous precipitations where they were preserved. Almost everywhere, even when no leaves or twigs are present, we find the stout subterranean rhizomas of the cane and the scouring rush, which, not having to be covered up, stood a far better chance to be preserved. But in numberless places the profusion of leaves is so great that there is too little rock between them to render it easy or even possible to separate them and obtain complete specimens. Above the plant beds, and occupying the intermediate strata between these more carbonaceous deposits of coal, reeds, and leaves, we find thicker and often massive beds of sandstone or marl, which seem to denote the presence over the former deposits of deep water produced by continued subsidence and the recession of the shore lines to distances too great for the access of the falling leaves, and the continuance of these conditions through prolonged periods of time.

If now we compare the flora of the great Laramie group, as thus described, with its invertebrate fauna, as elaborated by Dr. White, we find that in its *ensemble* the former is much more variable than the latter. The dicotyledonous species differ greatly at different parts of the area covered by the rocks of this group, so greatly, indeed, that it is not surprising that both Mr. Lesquereux and Dr. Newberry regard the Fort Union plants as belonging to a different age from those of the Wyoming and Colorado Laramie. Still, as I shall endeavor to show, this difference is not so great as it at first appears, and not sufficient to warrant this conclusion. In the first place, this difference appears chiefly in the dicotyledonous species, the only marked exception being that palms occur much more abundantly in the southern than in the northern districts. The same forms of reed-like plants are common at all points, while the Coniferæ do not differ more than might be expected on the theory of synchronism. The same is true of the abundant Equisetums, while very few ferns are found within the group.

Aside from the presence of palms the flora of the lower districts indicates a difference of climate greater than can be accounted for by the small difference of latitude. This is proved by the great prevalence of the genus Ficus and the presence of Cinnamomum, both of which are rare or wanting in the Fort Union group, while in the latter occur a great variety of Populus common to cold climates and the genus Corylus in abundance, absent from the Wyoming and Colorado beds. There are two ways in which these differences may be explained, or at least an explanation of them attempted, without denying the great difference of climate. In the first place, it is probable that the more southern parts of the Laramie sea were also much nearer the ocean on both the east and the west sides, and hence enjoyed a more equable climate, as well as one more moist, such that few of the trees and shrubs would lose their leaves by the action of frosts and that subtropical species, like the palms, the figs, and the cinnamons, could subsist. In the second place, it must be remembered that the Laramie period was a very prolonged one, and within it there was time for considerable alteration of climate on this continent or even on the whole globe. But even admitting that this was too slight to be perceptible, the changes that took place in the form of the continent and the distribution of land and water on it during that time might have been sufficient to produce marked effects and render the later floras of the Laramie age quite different from its earlier floras.

The Fort Union beds, containing the genera Corylus, Sapindus, and other forms of recent aspect not found in the Bitter Creek and Golden deposits, are believed to be high up in the series; and I have myself found and explored others within the general district included by that group which I have proved stratigraphically to occupy a considerably lower horizon, and in which these forms of recent aspect not only do not occur, but some of the most characteristic Laramie types, such as *Trapa microphylla* and *Pistia corrugata*, do occur, together with other forms not previously known as Laramie. In fact, it is well known that the Fort Union Laramie is everywhere thinner than the more southern deposits, none of the sections making it over 3,000 feet in thickness. The beds to which I refer rest immediately upon the typical Fox Hills, and therefore represent the lowest strata present in that section. I am not yet prepared to speak upon the precise affinities of this lower Fort Union flora, not having completed the elaboration of my material, but I can say this much, that besides containing some of the more southern Laramie forms, its general aspect indicates a much warmer climate than that which prevailed at the time of the deposition of the Corylus and Viburnum beds above.

Fully conceding, as I do, that the geological age of the Laramie group cannot, for the reasons stated, be proved by its flora alone, and holding that even great similarity of flora would not be conclusive as to synchronism of deposit, I have still thought it instructive, in view of the warmth with which the Cretaceous and Tertiary theories for the age of this group have been respectively advocated, to make some general comparisons of its flora with those of the extreme upper Cretaceous and lower Tertiary of those parts of the world where the stratigraphical position has been settled. In the several elaborate tables of distribution of the species of the Laramie group which Mr. Lesquereux has drawn up and employed to demonstrate its Eocene age, it is noticeable that he has seemed to ignore almost altogether the existence of a large upper Cretaceous flora lying entirely above the Cenomanian and its American equivalent, the Dakota group. In a paper which appeared in the American Journal of Science for April, 1884, I succeeded in getting together 260 species of Dicotyledons alone from this formation, which I designated as Senonian, and in a table published in the last Annual Report of the Geological Survey (1883-'84, p. 440) I showed that 354 Senonian species were then known, a flora slightly larger than that of the Laramie group. The principal localities from which this flora is derived are: the Iron sands of Aix-la-Chapelle, the Credneria beds of Blankenburg and Quedlinburg in the Harz Mountains, numerous deposits in Westphalia, the Gosau formation in Austria, the Lignites of Fuveau in Provence, France, the beds of Patoot, Greenland, and those of the Peace and Pine Rivers, British America, and of Vancouver and Orcas Islands on the Pacific coast. All of these beds are quite definitely fixed in the upper Cretaceous, those of Europe being well known. As regards the others, Professor Heer states that those of Patoot possess a molluscan fauna identical with that of the Fox Hills group of North America, and Mr. G. M. Dawson correlates those of the interior of British America with the Niobrara of Meek and Hayden, and those of the Pacific coast with the Fox Hills. All authorities agree, however, that all these beds are lower than the Laramie, and Dawson makes our Fox Hills the equivalent of the Maestricht and Faxoe beds, the white chalk, Danian, or extreme upper Cretaceous of Europe.

EXPLANATION OF THE TABLE OF DISTRIBUTION.

The following table aims to give all the fossil plants which have been thus far authentically described and recorded (1) in the Laramie group as above defined, (2) in the Senonian as last described, and (3) from the beds that have been unanimously referred to the Eocene. This last naturally excludes the Green River group, which is regarded as the American Eocene of the West by nearly all authorities except Mr. Lesquereux. As this one prominent author assigns the Laramie group (as defined by him) to the Eocene and places the Green River deposits in a higher formation, and as it is chiefly to test this question that the table and its discussion are intended, it would manifestly vitiate the argument to prejudge the question by adding the Green River group to the accepted Eocene.

In preparing this extensive table it has been my aim to embody in it as large an amount of information bearing not only upon the age and synchronism of the Laramie group but also upon all the collateral problems arising out of a study of the flora of that group as could be condensed into that amount of space. The plants are systematically arranged according to the latest botanical classifications, the names of the subordinate groups being entered in their proper places and distinguished by different type. The genera occupy separate lines and the number of species represented in each genus is given in each column on those lines, the occurrence of species in the several formations being denoted by the customary sign (+) employed by most authors for this object.

In the vertical arrangement the Laramie group is placed first merely because it is the group under immediate consideration, the Senonian next, because lowest, and because it is to its flora that it is especially desired to direct attention; the Eocene properly coming last. The first subdivision of the Laramie is intended to cover all the beds recognized by Mr. Lesquereux as belonging to that group. The Carbon and Evanston coal beds, excluded by him, follow, the two columns covering all the plants from the central and southern areas, the third being reserved for those of the northern districts, generally included under the name of Fort Union group. To this latter group, as undoubtedly belonging to a still more northern extension of it, I have assigned the species named by Sir J. W. Dawson,[1] as having been found in the Laramie of the British Provinces. These I have distinguished by the letters B. A. and the frequent coincidence of these letters with the regular sign for the species sufficiently attests the correctness of this conclusion. Most of the interrogation points occurring in this column represent cases where the fossils have been reported from the localities denominated "Six miles above Spring Cañon, near Fort Ellis, Montana," "Yellowstone Lake," "Elk Creek," and "Snake River." These plants are all classed by Mr. Lesquereux in his first and lowest group, or true Laramie, but upon careful investigation I am tolerably well satisfied that they belong to the Fort Union deposits. Their northern position and the known fact that these deposits extend far up the Yellowstone and Missouri Rivers would naturally favor this view, but it is the internal evidence afforded by the species themselves which is most convincing. A large proportion of the forms from this locality are also found in the true Fort Union beds and among these occurs *Platanus nobilis*, otherwise wholly characteristic of these beds. It is true that one species of Ficus and one palm occur here, but the genus Ficus is no longer excluded from the Fort Union group, while the occurrence of palms in that group has been recognized from the first.

The several acknowledged upper Cretaceous beds enumerated on a previous page are each given a separate column, and five of the most characteristic Eocene localities are also thus distinguished, the sixth column being devoted to several less important and some outlying beds referred to that age. In the last column the several localities which have been set off by some authors from the true Eocene and classed as Paleocene are grouped together. The principal beds of this class are the Travertines of the Lac de Rilly near Sézanne, to the east of Paris; the supra-lignitic deposits about Soissons, the "Sables de Bracheux;" and the so-called "Marnes Heersiennes" of Gelinden, all situated in Northern France and adjacent Belgian territory and immediately joining the only slightly lower Maestricht deposits.

The three broader columns which complete the body of the table

[1] On the Cretaceous and Tertiary Floras of British Columbia and the Northwest Territory. Transactions of the Royal Society of Canada, 1883, pp. 15–34, Pl. I–VIII (see list of Laramie plants on page 32).

merely sum up the data contained in these more detailed entries and exhibit the three formations side by side in compact form for ready comparison.

To this are added eleven columns for the purpose of indicating the vertical range of both the genera and the species. The first of these, in which the letter referring to the foot-note is substituted for the conventional sign, shows those forms which occur below the Cretaceous, the foot-notes showing the formations in which found. The headings of the other ten columns sufficiently explain themselves.

The geographical distribution of living genera, so far as practicable, and of genera closely allied to extinct ones, is also given in foot-notes, and the number of species of living phenogamous genera, as estimated by the highest botanical authorities, is indicated by figures in parenthesis. The importance and significance of this feature will be discussed in the proper place.

Table of distribution of Laramie, Senonian, and Eocene plants.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Brucheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Series I.—CRYPTOGAMIA.																																
CLASS I.—CELLULARES.																																
Fungi:																																
Sphæria, Hall	3								1				2						3	1	2					+		+				
cretacea, Heer									+											+												
lapidea, Lx	+																		+													
minutula, Sap													+								+											
myricæ, Lx	+																		+							+						
proxima, Sap													+								+											
rhytismoides, Lx	+																		+													
Sclerotium, Tode	1																		1									+				
rubellum, Lx	+																		+													
Lichenes:																																
Opegrapha, Ach	1																		1									+				
antiqua, Lx	+																		+													
Algæ:																																
Confervites, Schp				1																1		(*a*)					+	+				+
Aquensis, Deb. & Ett				+																+												
Thorea, Bory																3					3											
Brongniartii, M																+					+											
intermedia, M																+					+											
Janii, M																+					+											
Monemites, M																1					1											+
species, M																+					+											
Caulerpa, Lam *b*																	3				3											
annulata, Schp																	+				+											
arbuscula, Schp																	+				+											
arcuata, Schp																	+				+											

a Wealden. *b* Tropical seas.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Caulerpites, Schp	1			1												1	2		1	1	3	(*a*)										+
Araucaria, M																+					+											
bryoides, Ett				+																+												
filiformis, Heer																	+				+											
incrassatus, Lx	+																		+													
pyramidalis, St																	+				+											
Sphærococcites, Schp																	1				1	(*b*)						+				+
cæspitosus, F-O																	+				+											
Chondrites, St	2			5		7										7	6		2	11	13	(*c*)	+	+			+	+				+
affinis, Heer																	+				+											
antipathes, M																+					+											
bulbosus, Lx	+																		+													
Dalmaticus, Ett																+					+											
divaricatus, Deb. & Ett				+																+												
elegans, Deb. & Ett				+																+												
equisetoides, M																+					+											
furcillatus, St						+														+												
inclinatus, St																	+				+											
intricatus, Schp						+														+												
intricatus Fischeri, Heer																	+				+											
jugiformis, Deb. & Ett				+		+														+												
patulus, F-O																	+				+											
polymorphus, Hos. & Mck						+														+												
rhytiphlœoides, M																+					+											
rigidus, Deb. & Ett				+																+												
rigidus, M																+					+											
sphacelatus, M																+					+											
subcurvatus, Hos. & Mck						+														+												
subintricatus, Deb. & Ett				+																+												
subsimplex, Lx	+																		+													

a Silurian, Devonian. *b* Lias, Coral. *c* Muschelkalk, Lias, Oolite, Coral.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.							Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Monts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Chondrites, St.—Continued.																																
subverticillatus, Presl						+														+												
Targionii, St						+														+												
Targionii arbuscula, Heer																	+				+											
Targionii expansus, Heer																	+				+											
Zanardinii, M																+					+											
Delesseria, Lamx	1			1		1										7			1	1	7											
Agardhiana, Schp																+					+											
Bolcensis, M																+					+											
caulescens, Schp																+					+											
flabelliformis Schp																+					+											
fulva, Lx	+																		+													
Gazzolana, Schp																+					+											
Sandriana, M																+					+											
sphærococcoides, Schp																+					+											
Thierensi (Bosq.) Schp				+		+														+												
Tænidium, Heer						1											1			1	1											+
alysioides, Hos. & Mck						+														+												
Fischeri, Heer																	+				+											
Pterigophycos, M																2					2											+
Canossæ, M																+					+											
spectabilis, M																+					+											
Ceramites, M																1					1											+
species, M																+					+											
Pasinia, M																1					1											+
species, M																+					+											
Corallina, L												1									1	(a)										
(?) Micheloti, Schp												+									+											
Haliserites, Schp						1														1		(b)										+
contortuplicatus, Marck						+														+												

a Silurian, Oolite. *b* Devonian.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paléocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Zonarites, St.																3	1				4	(*a*)										+
alcicornis, F-O.																	+				+											
Brongniarti (M.) Schp																+					+											
flabellaris, Brongn																+					+											
stipitatus (M.) Schp																+					+											
Sargassum, Ag																1					1											
globuliferum, St.																+					+											
Fucus, L	1											6							1		6											
Brongniarti, Wat.												+									+											
eocenicus, Wat												+									+											
frondosus, Schp												+									+											
Jovii, Wat.												+									+											
lignitum, Lx	+																		+													
nobilis, Wat.												+									+											
Passyi, Wat.												+									+											
Halymenites, St.	3	1															4		3		4	(*b*)					+	+				+
flexuosus, F-O.																	+				+											
lumbricoides, Heer.																	+				+											
major, Lx.	+	+																	+													
minor, F-O.	+																+		+		+											
rectus, F-O.																	+				+											
striatus, Lx	+																		+													
Münsteria, St.																	6				6			+								+
annulata, Schafh.																	+				+											
caprina, Heer.																	+				+											
flagellaris, St.																	+				+											
geniculata, St.																	+				+											
Hæssii, St.																	+				+											
nummulitica, Heer.																	+				+											
Cylindrites, Göpp						1											1			1	1	(*c*)										+

a Lias. *b* Coral. *c* Rhetic.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Monte Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Cylindrites, Göpp.—Continued.																																
conicus, Hos. & Mck						+														+												
convolutus, F-O																	+				+											
Laminarites, St.												5				3					8	(*a*)										+
articulatus, Wat												+									+											
flabellaris, Wat												+									+											
irideæphyllus, M																+					+											
Jovii, Wat												+									+											
macrophyllus, M																+					+											
quadratus, Wat												+									+											
Scolopendra, M																+					+											
stipitatus, Wat												+									+											
Taonurus, F-O																	1				1	(*b*)										+
Brianteus, Villa																	+				+											
Aristophycos, M																1					1											+
Agardhianus, M																+					+											
Nemalionites, M																2					2											+
cristatus, M																+					+											
limacoides, M																+					+											
Characeæ:																																
Chara, Vaill *c*												8	1		1		1	1			12	(*d*)				+	+	+				
Archiaci, Wat												+									+											
Brongniarti, Al. Br												+									+											
depressa, Wat												+									+											
Dutemplei, Wat												+									+											
Grepini, Heer																	+				+							+				
gypsorum, Sap													+								+											
Helicteres, Brongn												+									+							+				
Lemani, Brongn												+									+											
Lyellii, Al. Br															+						+											

a Silurian, Lias. *b* Lias, Oolite. *c* Throughout temperate and tropical latitudes. *d* Oolite.

Table of distribution of Laramie, Senonian, and Eocene plants — Continued.

	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
Species represented.	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union Group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Chara, Vaill. — Continued.																																
minima, Sap																		+			+											
onerata, Wat												+									+											
Sparnacensis, Wat												+									+											
Muscineæ:																																
Marchantia, L *a*																		2			2											
gracilis, Sap																		+			+											
Sezannensis, Sap																		+			+											
Muscites, Brongn													2								2						+					+
pereger, Sap													+								+											
redivivus, Sap													+								+											
CLASS II.—VASCULARES.																																
Filices:																																
Sphenopteris, Brongn.	3										1					1			3	1	1	(*b*)		+	+	+	+	+				+
elongata, Newby											+									+												
eocenica, Ett																+					+											
Lakesii, Lx	+																		+													
membranacea, Lx	+																		+													
nigricans, Lx	+																		+													
Davallia, Sm. *c*			1																1													
tenuifolia, Sw			B. A.																+													
Davallites, Daws.											1									1												+
Richardsoni, Daws											+									+												
Hymenophyllum, Kaulf. *d*	1																		1			(*e*)			+							
confusum, Lx *e*	+																		+													
Neuropteris, Brongn											1									1		(*f*)										+

a Chiefly tropical.
b Subcarboniferous, Carboniferous, Permian, Rhetic, Lias, Oolite, Coral, Wealden.
c Tropical Asia, Japan, Malay Archipelago, New Zealand.
d America, Mexico, and West Indies to Patagonia, India, and East India Islands, Australasia, Mascarene Islands, Saint Helena, Pacific Islands.
e Carboniferous.
f Subcarboniferous, Carboniferous, Permian, Keuper, Oolite.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Neuropteris, Brongn.—Continued.																																
Castor, Daws											+									+												
Nilssonia, Brongn											1									1		(*a*)										+
lata, Daws											+									+												
Pecopteris, Brongn *b*							3		1		1									5		(*b*)	+	+	+			+				+
Bohemica, Corda									+											+				+								
heterophylla, (Ung.) Schp							+													+												
striata, St							+													+				+								
Zippei, Corda							+													+												
species, Daws											+									+												
Goniopteris, Presl	1														1	2			1		3	(*c*)					+	+				+
Dalmatica, Al. Br																+					+						+	+				
polypodioides, Ett	+															+			+		+							+				
Stiriaca, Al. Br															+						+											
Danæites, Göpp				1																1		(*d*)	+									+
Schlotheimii, Deb. & Ett				+																+												
Bonaventurea, Deb. & Ett				1																1												+
cardinalis, Deb. & Ett				+																+												
Zonopteris, Deb. & Ett				1																1												+
Gœpperti, Deb. & Ett				+																+												
Benizia, Deb. & Ett				1					1											1												+
calopteris, Deb. & Ett				+					+											+												
Raphælia, Deb. & Ett				1					1											1												+
neuropteroides, Deb. & Ett				+					+											+												
Pteridoleimma, Deb. & Ett				21				1												22												+
aneimiifolium, Deb. & Ett				+																+												
antiquum, Deb. & Ett				+																+												
Benincasæ, Deb. & Ett				+																+												
deperditum, Deb. & Ett				+																+												
dictyoides, Deb. & Ett				+																+												

a Rhetic. *b* Subcarboniferous, Carboniferous, Permian, Keuper, Rhetic, Lias, Oolite, Wealden. *c* Carboniferous, Permian. *d* Carboniferous.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Brachenx, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Pteridoleimma, Deb. & Ett.—Continued.																																
dubium, Deb. & Ett				+																+												
Elizabethæ, Deb. & Ett				+																+												
gymnorhachis, Deb. & Ett				+																+												
Haidingeri, Deb. & Ett				+																+												
Heissianum, Deb. & Ett				+																+												
Kaltenbachi, Deb. & Ett				+																+												
Komuckianum, Deb. & Ett				+																+												
leptophyllum, Deb. & Ett				+																+												
Michelisi, Deb. & Ett				+																+												
odontopteroides, Deb. & Ett				+																+												
orthophyllum, Deb. & Ett				+																+												
pecopteroides, Deb. & Ett				+																+												
pseudoadiantum, Deb. & Ett				+																+												
Ritzianum, Deb. & Ett				+																+												
Serresi, Deb. & Ett				+																+												
Waterkeyni, Deb. & Ett				+																+												
species, Sap								+												+												
Tænioptoris, Brongn									1		2	1								3	1	(*a*)					+					+
affinis, M												+									+						+					
deperdita, Heer									+											+												
Gibbsii, Newby											+									+												
plumosa, Daws											+									+												
Oleandridium, Schp												3									3	(*b*)										+
lobatum (Wat.) Schp												+									+											
Micheloti (Wat.) Schp												+									+											
obtusum (Wat.) Schp												+									+											
Carolopteris, Deb. & Ett				2																2												+
Aquensis, Deb. & Ett				+																+												
asplenioides, Deb. & Ett				+																+												

a Permian.

b Rhetic, Oolite, Wealden.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Monheimia, Deb. & Ett				2																2												+
Aquisgranensis, Deb. & Ett				+																+												
polypodioides, Deb. & Ett				+																+												
Polypodium, L *a*									1											1								+				
Graahianum, Heer									+											+												
Chrysodium, Fée (=Acrostichum, L) *b*															1						1											
Lanzeanum, Vis															+						+											
Podoloma, Ett															3						3											+
affine, Ett. & Gard															+						+											
lycopodioides, Ett. & Gard															+						+											
polypodioides, Ett. & Gard															+						+											
Glossochlamys, Ett															1						1											+
transmutans, Ett. & Gard															+						+											
Phegopteris, Fée									2						2					2	2			+								
Bunburii, Heer															+						+											
Grothiana, Heer									+											+												
Kornerupi, Heer									+											+												
præcuspidata, Ett. & Gard															+						+											
Cheilanthes, Sw *c*													1								1							+				
primæva, Sap													(?)								+											
Adiantum, L *d*									1						2			1		1	2								+	+		
apalophyllum, Sap																		+			+											
densinerve, Heer									+											+												
species, Ett. & Gard															+						+											
Hewardia, Smith (=Adiantum, L.)															1						1											
regia, Ett. & Gard															+						+											
Adiantites, Göpp				2				2			1					1				5	1	(*e*)				+	+	+				+
cassebeeroides, Deb. & Ett				+																+												

a Nearly cosmopolitan.
b Most tropical and warm regions; this section chiefly in Old World.
c Temperate and tropical America, Asia, Mediterranean region, Indian and Malay Archipelagos, Africa, Canaries and Madeiras, Bourbon.
d Nearly all temperate and tropical regions, chiefly in tropical South America.
e Subcarboniferous, Carboniferous.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Adiantites, Göpp—Continued.																																
Decaisneanus, Deb. & Ett.				+																+												
lacerus, Sap								+												+												
prælongus, Daws											+									+												
Schlehani, Ett																+					+											
Vedensis, Sap								+												+												
Blechnum, L *a*																1		1			2						+	+				
atavium, Sap																		+			+											
Braunii, Ett																+					+							+				
Pteris, L *b*	4								1		1		3		4		1		4	2	8		+	+		+	+	+		+		
Aquensis, Sap													+								+											
Bournensis, Ett. & Gard															+						+											
caudigera, Sap													+								+											
eocenica, Ett															+						+											
erosa, Lx	+																		+													
glossopteroides, Daws											+									+												
Hookeri, Heer															+						+							+				
Humii, Ett																	+				+											
lomariæformis, Sap													+								+											
longipennis, Heer									+											+				+								
Prestwichii, Ett. & Gard															+						+											
pseudopennæformis, Lx	+																		+							+						
Russellii, Newby	+																		+													
subsimplex, Lx	+																		+													
Asplenium, L *c*			1	3					2									2	1	5	2		+	+			+	+		+		
Brongniarti, Deb. & Ett				+																+												
cænopteroides, Deb. & Ett				+																+												
carphorum, Sap																		+			+											

a America (Mexico and Florida to Chiloe), Southern China, Himalayas, Malay Archipelago, temperate Australia, New Caledonia, Pacific Islands.

b Nearly all parts of the world, passing the Arctic Circle in Lapland.

c Nearly cosmopolitan, chiefly tropical and temperate.

Table of distribution of Laramic, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formation in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Asplenium, L.—Continued.																																
Fœrsteri, Deb. & Ett				+																+												
Pengelianum, Heer									+											+												
scrobiculatum, Heer									+											+												
tenerum, Lx			+																+													
Wegmanni, Brongn																		+			+											
Asplenites, Göpp															1						1											+
præallosuroides, Ett. & Gard															+						+											
Meniphyllum, Ett															1						1											+
elegans, Ett. & Gard															+						+											
Aspidium, Sw *a*							1		1		1									3				+			+	+	+	+		
Kennerlii, Newby											+									+												
Oerstedi, Heer									+											+				+								
Reichianum, St							+													+												
Woodwardia, Sm *b*	2														1				2		1							+	+	+		
latiloba, Lx	+																		+													
latiloba *minor*, Lx	+																		+													
? venosa, Ett. & Gard															+						+											
Dicksonia, L'Her *c*									1											1				+								
Grœnlandica, Heer									+											+				+								
Diplazium, Sw *d*	1																		1							+	+					
Mülleri, Heer	+																		+								+					
Lastrea, Presl *e*	2																		2							+	+					
Goldiana, Lx	+																		+													
intermedia, Lx	+																		+													
Gymnogramme, Desv *f*	2		1																2													

a Nearly cosmopolitan. *b* Temperate and tropical North America, Southern Europe, Eastern Asia, Madeiras, and Canaries. *c* Tropical America, temperate North America, Southern Europe, Pacific islands, Madeiras, Azores, Bourbon, Asia, Australasia, East India Islands, South Africa, New Hebrides. *d* Southern Asia, Himalayas, Japan, Indian and Malay Archipelagos, Angola, Mascarene Islands, Pacific islands, tropical America, Mexico, West Indies. *e* Nearly cosmopolitan. Species sometimes referred to Aspidium and Nephrodium. *f* All tropical regions, west coast North America to Vancouver Island, Cape Colony, Japan, Himalayas.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Hartz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Gymnogramme, Desv.—Continued.																																
Gardneri, Lx	+																		+													
Haydenii, Lx	+		(?)																+													
Alsophila, R. Br *a*																		3			3											
notabilis, Sap																		+			+											
Pomelii, Sap																		+			+											
thelypteroides, Sap																		+			+											
Cyathea, Sm *b*																		2			2			+								
debilis (Sap.) Schp																		+			+											
plenasiæformis (Sap.) Schp																		+			+											
Marattia, Sm *c*															1						1											
Hookeri, Ett. & Gard															+						+											
Hemitelia, R. Br *d*																		2			2											
longæva (Sap.) Schp																		+			+											
proxima (Sap.) Schp																		+			+											
Gleichenia, Sw *e*				1	3				4						1					7	1	(*f*)	+	+	+							
acutiloba, Heer					+															+				+								
Gieseckiana, Heer									+											+			+	+								
Hantonensis, Wanklyn															+						+											
Kurriana, Heer					+															+				+	+							
obtusata, Heer									+											+												
protogæa, Deb. & Ett				+																+												
Vahliana, Heer									+											+												
Zippei (Corda) Heer					+				+											+			+	+								
Anemia, Sw *g*															1			1			1											

a Western America, Mexico to Chili and Juan Fernandez, West Indies, India, Indian and Malay Archipelagos, Australia, New Zealand, tropical Africa.
b Southeastern Asia, Malay Archipelago, Australia, New Zealand, Pacific islands, tropical America.
c Mexico and West Indies to tropical South America, East India Islands, Australia, New Caledonia, Pacific islands, South Africa.
d Tropical America, Mexico, West Indies, Indian Archipelago, South Pacific islands, New Zealand, South Africa, Madagascar.
e Tropical and subtropical regions, temperate South America to Straits of Magellan.
f Oolite.
g Tropical and subtropical America, West Indies, Uruguay, Natal.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Anemia, Sw.—Continued.																																
subcretacea (Sap.) Ett. & Gard															+			+			+											
Didymosorus, Deb. & Ett				3																3				+								+
comptoniæfolius, Deb. & Ett				+																+				+								
gleichenioides, Deb. & Ett				+																+												
varians, Deb. & Ett				+																+												
Lygodium, Sw *a*	3			1											1		1	2	3	1	3				+	+		+				
capillare, Wat																		+			+											
compactum, Lx	+																		+													
crassicostatum, Wat																		+			+											
cretaceum, Deb. & Ett				+																+												
Kaulfussi, Heer															+		+				+											
Marvinei, Lx	(?)																		+													
neuropteroides, Lx	(?)																		+							(?)						
Osmunda, L *b*	2					1			1						1			1	2	2	2						+	+		+		
affinis, Lx	+																		+													
arctica, Heer									+											+												
eocenica, Sap																		+			+											
Haldemiana, Hos. & Mck						+														+	+											
lignitum, Giebel sp															+						+							+				
major, Lx	+																		+													
Osmundites, Carr															1						1											+
Dowkeri, Carr															+						+											
Ophioglossum, L *c*									1								1			1	1											
eocenicum (M.) Schp																	+				+											
granulatum, Heer									+											+												

a Tropical America, Eastern United States, West Indies, Southern and Eastern Asia, East India Islands, Australia, New Zealand, Angola, Madagascar, Pacific islands.

b America from Canada to Brazil, Northern Europe, Northern Asia, Eastern and Southeastern Asia, Barbary, Mascarene Islands, South Africa, Azores (few tropical and only 1 south temperate).

c Temperate and tropical America, West Indies, Lapland to Japan and India, East India Islands, Australia, New Zealand, New Caledonia, east tropical and Southern Africa, Mascarene and Pacific islands.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Tempskya, Corda					1															1												+
cretacea, Hos. & Mck.					+															+												
Onoclea, L *a*			1												1				1		1							+				
Hebraidica, Forbes															+						+											
sensibilis, L.		{	B. A. +	}															+												+	
Rhizocarpeæ:																																
Salvinia, Mich *b*	1																		1							+		+				
attenuata, Lx.	+																		+													
Equisetaceæ:																																
Equisetum, L *c*	2	1	3						1							1			5	1	1	(*d*)		+		+	+	+				
amissum, Heer									+											+			+	+								
Erbreichii (Ett.) Schp																+					+											
globulosum, Lx.			+																+													
Haydenii, Lx	(?)	+																	+							+						
lævigatum, Lx.	+																		+													
limosum, L			(?)																+												+	
species, Daws.			B. A.																+													
Physagenia, Heer *e*			1																1									+				+
Parlatorii, Heer.			B. A.																+									+				
Lycopodiaceæ:																																
Psilotites, Gold			1																1			(*f*)										+
inermis (Newby) Schp			+																+													
Selaginella, Beauv *g*	3																		3					+								
Berthoudi, Lx.	+																		+													
falcata, Lx	+																		+													
laciniata, Lx	+																		+													

a Temperate Eastern North America (Florida to Canada), Northern and Central Europe and Asia, Japan, mountains of Southeastern Asia.
b Northern Hemisphere, tropical South America.
c Chiefly north temperate regions; absent from nearly the whole Southern Hemisphere.
d Keuper, Rhetic, Lias, Oolite, Wealden.
e Regarded by Schimper as a form of Equisetum.
f Carboniferous.
g Most cold countries.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Series II.—PHÆNOGAMIA.																																
CLASS I.—GYMNOSPERMÆ.																																
Cycadaceæ:																																
Zamites, Brongn *a*								2												2		(*b*)	+	+			+	+				+
serotinus, Sap								+												+												
species, Sap								+												+												
Zamiostrobus, Endl	1						1												1	1		(*c*)	+	+			+					+
gibbus (Reuss) Schp							+													+				+								
mirabilis, Lx	+																		+													
Dioonites, Born *d*										1										1		(*e*)										+
borealis, Daws										+										+												
Pterophyllum, Brongn					1															1		(*f*)		+								+
Ernestinæ, Stiehl					+															+												
Cycadites, Kraus										1										1		(*g*)	+	+				+				+
Unjiga, Daws										+										+												
Cycadoxylon						1														1												+
Westfalicum, Hos. & Mck						+														+												
Coniferæ:																																
Abietites, Göpp *h*	1		2		1														2	1		(*i*)	+	+	+			+	+			+
curvifolius, Dunk					+															+												
dubius, Lx	+		(?)																+													
setiger, Lx			(?)																+													
Tsuga, Carr *j*															1						1											
Heerii, Ett. & Gard															+						+											
Pinus, L *k*						1						2	6		7					1	15		+	+	+	+	+	+	+	+		

a (Zamia 30.) Tropical and subtropical North America.
b Lias, Oolite, Coral, Wealden.
c Oolite, Coral, Wealden.
d (Dioon 2.) Mexico.
e Permian, Keuper, Rhetic, Lias, Oolite, Wealden.
f Keuper, Rhetic, Oolite, Wealden.
g Carboniferous, Rhetic, Lias, Oolite, Wealden.
h (Abies 18.) Extratropical, Northern Hemisphere.
i Wealden.
j (5) 2 Asia, 3 North America.
k (70) Extratropical, North America. Very few tropical Eastern Asia, West Indies, and Central America.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Pinus, L.—Continued.																																
Aquensis, Sap													+								+											
Bailyi, Ett. & Gard															+						+											
Bowerbankii (Carr.) Ett. & Gard															+						+											
Coquandi, Sap													+								+											
Defrancei, Brongn												+									+											
diversifolia, Sap													+								+											
Dixoni (Bow.) Ett. & Gard															+						+											
gracilis, Sap													+								+											
humilis, Sap													+								+											
macrocephalus (L. & H.) Ett. & Gard															+						+											
monasteriensis, Hos. & Mck						+														+												
ovata, L. & H															+						+											
Plutonis, Baily															+						+						+					
Prestwichii, Ett. & Gard															+						+											
robustifolia, Sap													+								+											
Sequanensis, Wat												+									+											
Araucaria, Juss *a*															1						1	(*b*)			+							
Göpperti, St															+						+											
Araucarites, St					1							1								1	1											+
Duchartrei, Wat												+									+											
Hartigi, Dunk					+															+												
Agathis, Salisb. (Dammara, Lamb) *c*									2											2				+								
macrosperma, Heer									+											+												
microlepis, Heer									+											+				+								
Cunninghamites, St. *d*				1	1	2														2			+	+				+				+
recurvatus, Hos. & Mck						+														+												
squamosus, Heer				+	+	+														+												

a (10) South America, Australia, New Caledonia, and South Pacific islands.
b Oolite, Wealden.
c (8–10) Malay Archipelago, Fiji Islands, New Caledonia, New Zealand, and tropical East Australia.
d (Cunninghamia 1.) Japan and China.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Podocarpus, L'Her *a*												2	5		5	1					12					+	+	+				
argillæ-Londonis, Ett. & Gard															+						+											
elatus, Gard															+						+											
elegans (Delabarpe) Ett. & Gard															+						+											
eocenica, Ung															+	+					+					+	+	+				
Fyeensis, Crié												(?)									+											
gracilis, Sap													+								+											
gypsorum, Sap													+								+											
incerta, Ett. & Gard															+						+											
linearis, Sap													+								+											
Lindleyana, Sap													+								+						+					
proxima, Sap													+								+											
Suessionensis, Wat												+									+											
Ginkgo, L. (Salisburia, Sm.) *b*			1								2				1		1		1	2	2			+				+				
Baynesiana, Daws											+									+												
binervata, Lx																	+				+											
eocenica, Ett. & Gard															+						+											
polymorpha, Lx			(?)								+								+	+												
Torreya, Arn *c*											1									1					+				+			
dicksonioides, Daws											+									+												
Taxus, L *d*															1						1							+	+	+		
Swanstoni, Ett. & Gard															+						+											
Taxites, Brongn			2						1										2	1								+				+
pecten, Heer									+											+												
occidentalis, Newby			B. A.																+													
Olriki, Heer			B. A.																+									+				
Cephalotaxus, Sieb. & Zucc *e*									1											1												
insignis, Heer									+											+												

a (60) Extratropical Southern Hemisphere, mountainous and Eastern Asia, mountains of tropical America (rare); absent from Southern Europe, Western Asia, Northern Africa, and North America.

b (1) China.

c (3–4) North America, Japan, China.
d (6–8) Temperate Northern Hemisphere.
e (4) 3 Japan, 1 China.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Athrotaxis, Don *a*															2						2											
Couttsiæ (Heer) Ett. & Gard															+						+											
subulata, Ett. & Gard															+						+											
Taxoxylon, Kraus						1														1												+
Halternianum, Hos. & Mck						+														+												
Solenostrobus, Endl.															3						3											+
corrugatus (Bow.) Endl															+						+											
semiplotus (Bow.) Endl															+						+											
sulcatus (Bow.) Endl															+						+											
Frenelopsis, Schenk						1														1		(*b*)	+									+
Königii, Hos. & Mck						+														+												
Cyparissidium, Heer							2		2											4			+	+								+
cretaceum, Schenk							+													+												
gracile, Heer									+											+			+	+								
mucronatum, Heer									+											+												
Suessii, Schenk							+													+												
Sequoia, Endl. *c*	5		2		2	2			6	1	1				3	1			6	9	4	+	+	+	+	+	+	+				
acuminata, Lx	+																		+													
biformis, Lx	+																		+													
brevifolia, Heer	+																		+									+				
concinna, Heer									+											+												
Couttsiæ, Heer															+						+							+				
fastigiata, Heer									+											+												
Heerii, Lx																			+													
Langsdorfii, Brongn	+	{	(?) B. A. +	}					+		+				+				+	+	+							+				
Legdensis, Hos. & Mck						+														+												
longifolia, Lx	+																		+													
macrolepis, Heer									+											+												
pectinata, Heer					+															+												

a (3) Tasmania. *b* Oolite. *c* (2) California.

Table of distribution of Laramie, Senonian, and Eocene plants — Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Monts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Sequoia, Endl.—Continued.																																
Reichenbachi (Gein.) Heer					+	+				+										+			+	+								
rigida, Heer									+											+			+	+								
Sternbergi (Göpp.) Heer																+					+						+	+				
subulata, Heer									+											+				+								
Tournalii, Brongn															+						+											
Taxodium, Rich. (including Glyptostrobus, Endl.) *a*			3						1		2				1		1		3	3	1		+			+	+	+	+			
cuneatum, Newby											+									+												
distichum miocenum, Heer			+																+							+	+	+			?	
Europæum, Brongn		{	B. A. +	}											+		+		+		+					+	+	+	+			
intermedium, Heer									+											+												
occidentale, Newby			+																+													
species, Daws											+									+												
Cryptomeria, Don *b*															1						1											
Sternbergii, Göpp															+						+											
Geinitzia, Endl					1		1		1											3			+									+
cretacea, Endl							+													+				+								
formosa, Heer					+															+												
hyperborea, Heer									+											+												
Juniperus, L *c*													1								1			+			+	+				
ambigua (Sap.) Schp													+								+						+					
Cupressus, L *d*															2						2											
Pritchardi (Göpp.) Ett. & Gard															+						+											
taxiformis, Ung															+						+											
Thuya, L. (including Chamæcyparis, Spach.) *e*			2															1	2		1						+	+	+			
Belgica, Sap. sp																		+			+											

a (3) 2 North America and Mexico, 1 China.
b (1) Japan and China.
c (25) Temperate and frigid and mountainous tropical Northern Hemisphere.
d (12) Temperate Asia, Southeastern Europe, North America, and Mexico.
e (12) Extratropical North America and Eastern Asia.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Thuya, L. (including Chamæcyparis, Spach.)—Continued.																																
gracilis, Newby			+																+													
interrupta, Newby			B. A. +																+													
Libocedrus, Endl *a*															1						1			+			+	+				
adpressa, Ett. & Gard															+						+											
Callitris, Vent. (including Widdringtonia, Endl., Cupressinites, Bow.) *b*	1								1				3		6				1	1	9					+	+	+				
brachyphylla, Sap. sp													+								+											
Brongniartii, Endl													+								+						+	+				
complanata, Lx	+																		+													
curta (Bow.) Ett. & Gard															+						+											
elongata, Bow. sp															+						+											
Ettingshauseni, Gard															+						+											
globosa, Bow. sp															+						+											
Heerii, Sap													+								+						+					
recurvata, Bow. sp															+						+											
Reichii, Ett. sp									+											+												
subfusiformis, Bow. sp															+						+											
Moriconia, Deb. & Ett				1					1											1				+								+
cycloloxon, Deb. & Ett				+					+											+				+								
Inolepis, Heer									1											1					+							+
affinis, Heer									+											+												

a (8) 2 Chile, 2 New Zealand, 1 New Caledonia, 1 Japan, 1 China, and 1 California.

b (14) Africa, Madagascar, Australia, and New Caledonia.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
CLASS II.—ANGIOSPERMÆ.																																
Subclass I:—MONOCOTYLEDONES.																																
Gramineæ:																																
Phragmites, Trin *a*	1	1	2								1								3	1					+	+		+		+		
Alaskana, Heer			(?)																+													
cordaiformis, Daws											+									+												
Œningensis, Al. Br	+	+																	+							+	+	+				
species, Newby		{	B. A. +	}															+													
Pseudophragmites, Sap													1								1							+				+
arundinaceus, Sap													+								+											
Arundo, L *b*	1								1			1				1		1	1	1	2			+		+	+	+				
Gœpperti, Heer												+				+					+					+	+	+				
Grœnlandica, Heer									+											+				+								
obtusa, Lx	+																		+													
Papilloni (Wat.) Schp																		+			+											
Arundinites, Sap												1					1				2						+					+
deperditus (Heer) Schp																	+				+											
dubius (Wat.) Schp												+									+											
Bambusium, Ung																	1				1	(*c*)										+
longifolium, Heer																	+				+											
Panicum, L *d*													1								1							+				
multiflorum, Sap													+								+											
Poacites, Brongn												2	9					3			14					+	+	+				+
carcifolius, Sap													+								+											
deletus, Wat												+									+											

a (2) Temperate and subtropical regions; rare in the tropics.
b (6–7) Mediterranean region, East Indies, tropical America, Malay Archipelago, Madagascar, New Zealand, Andes, and Antarctic America.
c Lias.
d (280) In all warm and temperate regions; least abundant in Asia and temperate North America.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Poacites, Brongn.—Continued.																																
distichus, Sap													+								+											
glumaceus, Sap													+								+											
nervosus, Sap													+								+											
obsoletus, Wat												+									+											
ovatus, Sap													+								+											
paucinervis, Wat																		+			+											
protogæus, Wat																		+			+											
refertus, Sap													+								+											
restiaceus, Sap													+								+											
Roginei, Wat																		+			+											
Schimperi, Heer													+								+											
triticeus, Sap													+								+											
Cyperaceæ:																																
Carex, L *a*	1																		1								+	+				
Berthoudi, Lx	+																		+													
Scirpus, L *b*			1																1											+		
species, Daws			B. A.																+													
Cyperacites, Schp													2			1		1			4					+	+	+	+			+
Bolcensis, M																+					+											
palæostachyus, Sap													+								+											
schœnoides, Sap													+								+											
Sezannensis, Sap																		+			+											
Rhizocaulon, Sap								1					1							1	1						+	+				+
gypsorum, Sap													+								+											
macrophyllum, Sap								+												+												
Eriocaulonaceæ:																																
Eriocaulon, L *c*	1																		1													
porosum, Lx	+																		+													

a (500) Temperate and frigid regions, mountains in tropics.
b (300) All parts of the world.
c (100) All warmer parts of the world, except Northern Africa and Southern Europe; chiefly tropical.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.							Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Monte Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Naiadaceæ:																																
Zosterites, Brongn *a*												1				1					2	(*b*)					+	+				+
affinis, Ett																+					+						+					
Lamberti, Wat												+									+											
Thalassocharis, Deb				1		2														3												+
Bosqueti, Deb						+														+												
Mülleri, Deb				+																+												
Westfalica, Hos. & Mck						+														+												
Halochloris, Ung																1					1						+					+
cymodoceoides, Ung																+					+						+					
Posidonia, Koen *c*						1														1												
cretacea, Hos. & Mck						+														+												
Caulinites, Brongn	2	1	1									2				3		1	2		6			+				+				+
Catuli, M																+					+											
digitatus, Wat																		+			+											
fecundus, Lx	+																		+													
loiopitys, M																+					+											
nodosus, Ung												+									+							+				
Parisiensis, Brongn												+									+											
rhizoma, M																+					+											
sparganioides, Lx	+	+	(?)																+													
Sphænophora, M																4					4											+
crassa, M																+					+											
Ettingshauseni, Vis																+					+											
gracilis, M																+					+											
lacisioides, M																+					+											
Potamogeton, L *d*									1			8	3		1	2		1		1	14					+	+	+				
cæspitans, Sap													+								+											
crebrinervis, Wat												+									+											
cretaceus, Heer									+											+												

a (Zostera 4) Temperate seas of the Old World. *b* Lias. *c* (2) 1 Mediterranean region; 1 Australia. *d* (50) Nearly all parts of the world.

6 GEOL——30

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Potamogeton, L.—Continued.																																
enervis, Wat												+									+											
eocenicus, Wat												+									+											
erectus, Sap													+								+											
extinctus, Wat												+									+											
filiformis, Sap													+								+											
microphyllus, Wat												+									+											
multinervis, Brongn												+									+											
najadum, Ung																+					+											
quadrilaterus, Wat												+									+											
rarinervis, Wat												+									+											
thalictroides, Wat															+			+			+											
Tritonis, Ung																+					+											
Alismaceæ:																																
Alismacites, Sap *a*													1								1											+
lancifolius, Sap													+								+											
Lemnaceæ:																																
Lemna, L *b*	1		1																1													
scutata, Daws	+		B. A.																+							+						
Aroideæ:																																
Pistia, L *c*	1																		1													
corrugata, Lx	+																		+													
Pistites, Hos. & Mck						1														1												+
loriformis, Hos. & Mck						+														+												
Limnophyllum, Hos. & Mck						2														2												+
lanceolatum, Hos. & Mck						+														+												
primævum, Hos. & Mck						+														+												
Typhaceæ:																																
Typhæloipum, Ung *d*								1												1												+

a (Alisma 10) Europe, Northern Asia, tropical Africa, North America, Australia.
b (7) Temperate and tropical regions.
c (1) Tropical fresh waters, except Australia and Pacific islands.
d (Typha 10) Temperate and tropical regions.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Brackeux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Typhæloipum, Ung.—Continued.																																
primævum, Sap								+												+												
Sparganium, L *a*													2								2			+			+	+				
strictum, Sap													+								+											
Stygium, Heer													+								+						+	+				
Pandanaceæ:																																
Pandanus, L *b*					1															1				+			+					
Simildæ, Stiehl					+															+												
Ludoviopsis, Sap *c*																		2			2											+
discerpta, Sap																		+			+											
geonomæfolia, Sap																		+			+											
Kaidacarpum, Carr									1											1												+
cretaceum, Heer									+											+												
Palmæ:																																
Latanites, M *d*																1					1						+					+
parvulus, M																+					+											
Calamopsis, Heer *e*																	1				1							+				+
Danai, Lx																	+				+							+				
Sabal, Adans. (incl. Sabalites, Lx.) *f*	3		2								1	2	1	1	1	2	3	1	4	1	9						+	+				
Andegaviensis, Schp																	+				+											
Campbellii, Newby	+		+																+									+				
fructifer, Lx. sp	+																		+													
Grayana, Lx. sp	+																+		+		+											
Hæringiana (Ung.) Schp																+					+						+					
imperialis, Daws											+									+												
Latania, Rossm. sp																+					+						+					
major, Ung													+		+						+						+	+				

a (6) Temperate and subfrigid Northern Hemisphere and Australia.
b (50) Malay Archipelago, Mascarene and Seychelles Islands, Australia and Oceanica (few); West Indies 1.
c (Carludovica 30) Tropical America, West Indies.
d (Latania 3) Mascarene Islands.
e (Calamus 200) Tropical and subtropical Asia, Africa (few); Australia (few).
f (6) Tropical and subtropical North America, West Indies, Venezuela.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Monte Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Sabal, Adans. (incl. Sabalites, Lx.)—Continued.																																
microphylla, Sap														+							+											
præcursoria (Sap.) Schp												+									+											
primæva, Schp												+					+				+											
Suessionensis (Wat.) Schp																		+			+											
species, Newby			+																+													
Flabellaria, St	2						1					1	3				1		2	1	4				+	+	+	+				+
chamæropifolia, Göpp							+													+												
costata, Sap													+								+											
eocenica, Lx	+																		+		+											
Goupili, Wat												+									+											
Lamanonis, Brongn													+				+				+											
litigiosa, Sap													+								+											
Zinkeni, Heer	+																		+								+					
Palæophœnix, Sap *a*														1							1											+
Aymardi, Sap														+							+											
Nipadites, Bow *b*								2				1			3		1			2	4											+
Burtini, Brongn															+		+				+											
curtus, Sap								+												+												
Heberti, Wat												+									+											
Parkinsonis, Bow															+						+											
provincialis, Sap								+												+												
semiteres, Bow															+						+											
Castellina, M																5					5											+
ambigua, M																+					+											
compressa, M																+					+											
elliptica, M																+					+											
incurva, M																+					+											
macrocarpa, M																+					+											

a (Phœnix 12) Tropical and subtropical Asia and Africa.

b (Nipa 1) Tropical Asia, Ceylon, Philippine Islands, New Guinea, tropical Australia.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Geonomites, Lx *a*	3		1																4													+
Goldianus, Lx	+																		+													
Schimperi, Lx			?																+													
tenuirachis, Lx	+																		+													
Ungeri, Lx	+																		+													
Oreodoxites, Lx *b*	1																		1													+
plicatus, Lx	+																		+													
Palmacites, Brongn												3	1					1			5			+			+	+				+
Aquensis, Sap													+								+											
annulatus, Brongn												+									+											
arenarius, Wat												+									+											
Axonensis, Wat												+									+											
echinatus, Brongn																		+			+											
Aularthrophyton, M																1					1											+
formosum, M																+					+											
Wetherellia, Bow															1						1											+
variabilis, Bow															+						+											
Tricarpellites, Bow															7						7											+
acicularis, Bow															+						+											
communis, Bow															+						+											
crassus, Bow															+						+											
curtus, Bow															+						+											
gracilis, Bow															+						+											
patens, Bow															+						+											
rugosus, Bow															+						+											
Palmocarpon, Lx	6																		6							+						+
commune, Lx	+																		+													
compositum, Lx	+																		+													
corrugatum, Lx	+																		+													
Mexicanum, Lx	+																		+													

a (Geonoma 100) Tropical America.

b (Oreodoxa 5) Tropical America.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Palmocarpon, Lx.—Continued.																																
subcylindricum, Lx	+																		+													
truncatum, Lx	+																		+													
Liliaceæ:																																
Eolirion, Schenk						1														1												+
nervosum, Hos. & Mck						+														+												
Dracænites, Sap *a*													2								2						+					+
Brongniartii, Sap													+								+											
sepultus, Sap													+								+											
Majanthemophyllum, Web *b*									3							1				3	1			+			+	+				+
athesimum, M																+					+											
cretaceum, Heer									+											+												
lanceolatum, Heer									+											+												
pusillum, Heer									+											+												
Smilax, L *c*	1	1											1					1	1		2						+	+		+		
grandifolia, Ung	+	+																	+									+				
Lyellii, Wat. sp																		+			+											
rotundiloba (Sap.) Schp													+								+											
Scitamineæ:																																
Musophyllum, Göpp *d*								1					1					1		1	2					+	+	+				+
Axonense, Wat																		+			+											
longævum, Sap								+												+												
speciosum, Sap													+								+											
Cannophyllites, Brongn *e*																		1			1											+
Ungeri, Wat																		+			+											
Zingiberites, Heer *f*	1																		1					+				+				+
dubius, Lx	+																		+													

a (Dracæna 35) Warmer regions of the Old World.
b (Maianthemum 1) Temperate Northern Hemisphere.
c (187) Tropical and temperate regions.
d (Musa 20) Tropical regions of the Old World.
e (Canna 30) Tropical and subtropical America.
f (Zingiber 30) East Indies, Malay Archipelago, Mascarene and Pacific islands.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Amomophyllum, Wat *a*																		1			1											+
tenue, Wat																		+			+											
Hydrocharideæ:																																
Ottelia, Pers *b*	1											1							1		1											
Americana, Lx	+																		+													
Parisiensis, Sap												+									+											
Subclass II.—DICOTYLEDONES.																																
Division I.—Apetalæ.																																
Salicineæ:																																
Populus, L *c*	8	6	15			1			2		6		1	1			2	3	23	9	7		+	+	+	+	+	+	+	+		
acerifolia, Newby			B. A. +																+													
arctica, Heer	(?)	+	B. A. +																+							+		+				
balsamoides, Göpp			+																+									+				
balsamoides eximia, Göpp			+																+									+				
cordata, Newby			+																+													
cuneata, Newby			+																+													
decipiens, Lx		+																	+													
denticulata, Heer									+											+												
glandulifera, Heer			+																+													
Heerii, Sap													+								+					+						
Hookeri, Heer			B. A.																+									+				
lævigata, Lx	+	(?)																	+													
latior truncata, Al. Br			+																+													
Ligeri, Sap														+							+											

a (Amomum 50) Tropical Asia, Africa, Australia, and Pacific islands.
b (7) Tropical Asia, Japan, Australia, Mascarene Islands; tropical and subtropical Africa, Brazil.
c (18) Europe, middle and northern Asia, and mountains of tropical Asia, North America, Mexico.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Populus, L.—Continued.																																
longior, Daws											+									+												
melanaria, Heer	+																		+									+				
melanarioides, Lx	+																		+													
modesta, Wat																		+			+											
monodon, Lx	+																+		+		+											
mutabilis ovalis, Heer	+	+																	+									+				
mutabilis repando-crenata, Heer																	+				+							+				
Nebrascensis, Newby			+																+													
nervosa, Newby			+																+													
primigenia, Sap																		+			+											
protozaddachii, Daws											+									+												
rectinervata, Daws											+									+												
rhomboidea, Lx											+									+												
Richardsoni, Heer			B. A. +																+							+		+				
rotundifolia, Newby			+																+													
smilacifolia, Newby			+																+													
Stygia, Heer									+											+				+								
subrotundata, Lx	+	+																	+													
Suessionensis, Wat																		+			+											
tremulæformis, Hos. & Mck						+														+												
trinervis, Daws											+									+												
Ungeri, Lx	+	+																	+													
Zaddachi, Heer			+																+							+		+				
species, Daws											+									+												
Populites, M. emend										1										1					+							+
cyclophylla, Heer										+										+					+							
Salix, L [a]	1		2		2						2		1				2	6	3	4	9				+	+	+	+	+	+		
angusta? Al. Br			(?)																+							+		+				

[a] (160) Temperate and frigid Northern Hemisphere; more rare in tropics; very few in Southern Hemisphere; 1 Chile; none in Malay Archipelago or South Pacific islands.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.							Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Salix, L.—Continued.																																
Aquensis, Sap													+								+											
Axonensis, Wat																		+			+											
crebrinervia, Wat																		+			+											
Gœtziana, Heer					+															+												
Hartigi (Dunk.) Schp					+															+												
integra, Göpp	+																		+									+				
Islandica, Lx											+									+								+				
longinqua, Sap																		+			+											
Pacifica, Daws											+									+												
primæva, Sap																		+			+											
Ræana, Heer			B. A.																+									+				
socia, Sap																		+			+											
stupenda, Sap																		+			+											
tabellaris, Lx																	+				+											
Worthenii, Lx																	+				+											
Cupuliferæ:																																
Fagus, L *a*	1	1								1							1	2	1	1	3			+	+	+	+	+	+	+		
dubia, Wat																		+			+											
eocenica, Wat																		+			+											
Feroniæ, Ung	+	+																	+							+	+	+				
protonucifera, Daws										+										+												
Wilkinsonia, Ett																	+				+											
Castanea, Gærtn *b*																	1	1			2			+		+	+	+				
eocenica, Wat																		+			+											
Moorii (Lx.) Schp																	+				+											
Castanopsis, Spach *c*																	1				1											
mephitidioides (Gey.) Ett																	+				+											

a (15) Temperate and more frigid regions of both Hemispheres.

b (2) Temperate Northern Hemisphere, Asia, Europe, North America.

c (25) India, China, Malay Archipelago, 1 California.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Brachleux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Quercus, L *a*	8	5	12			16			7		4	1	6		2	1	11	11	23	27	29			+	+	+	+	+	+	+		
acrodon, Lx		+																	+													
angustiloba, Al. Br	+																		+								+	+				
antecedens, Sap													+								+											
?antiqua, Newby			B. A.																+						+							
arciloba, Sap. & Mar																		+			+											
asymetra, Hos. & Mck						+														+												
Axonensis, Wat																		+			+											
Benzoin, Lx											+									+												
bifurca, Wat																		+			+											
castanoides, Hos. & Mck						+														+												
castanopsis, Newby			+																+													
chlorophylla, Ung	+		(?)													+	+		+		+							+				
Cleburni, Lx	+																		+													
cuneata, Hos						+														+												
cuspidigera, Heer									+											+												
Darwinii, Ett																	+				+											
denticulata, Heer									+											+												
Dentoni, Lx			+																+													
diplodon, Sap. & Mar																		+			+											
divergens, Wat																		+			+											
dryandræfolia, Marck						+														+												
Drymeja, Ung																	+				+					+	+	+				
drymejoides, Ett																	+				+											
dubia, Newby			+																+							(?)						
elæna, Ung													+								+					+	+	+				
elliptica, Sap													+								+							+				
Ellisiana, Lx			(?)																+													
formosa, Hos. & Mck						+														+												

a (300) Europe, temperate and tropical Asia, North America, mountains of Central America and United States of Colombia; Africa except Mediterranean region; Mascarene Islands, Australia, Pacific islands, and New Guinea.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Quercus—Continued.																																
fraxinifolia, Lx.			(?)																+													
furcinervis (Rossm.) Ung.															+		+				+						+	+				
Godeti, Heer			(?)																+									+				
gracilis, Newby	+																		+													
Haydenii, Lx.		(?)																	+													
hieracifolia, Hos. & Mck						+														+												
Hookeri, Ett.																	+				+											
iliciformis, Hos. & Mck.						+														+												
Johnstoni, Heer									+											+												
Lamberti, Wat.																		+			+											
latissima, Hos						+														+												
Langeana, Heer									+											+												
laurifolia, Newby			+																+													
Legdensis, Hos						+														+												
Lonchitis, Ung.															+		+				+						+	+				
longifolia, Hos						+														+												
Loozi, Sap. & Mar																		+			+											
Lyellii, Heer																	+				+							+				
macilenta, Sap												+									+											
Marconi, Heer									+											+												
multinervis, Lx.											+									+												
myrtillus, Heer									+											+												
negundoides, Lx.		+																	+													
neriifolia, Al. Br.	+																		+							+	+	+				
Olafseni, Heer	+		+																+									+				
palæophellos, Sap.													+								+											
parallelinervis, Wat.																		+			+											
parceserrata, Sap. & Mar																		+			+											
Patootensis, Heer									+											+												
paucinervis, Wat.																		+			+											

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Quercus—Continued.																																
paucinervis, Hos						+														+												
Pealei, Lx			(?)																+													
platania, Heer		+																	+									+				
platinervis, Lx											+									+												
præphilippinensis, Ett																	+				+											
retracta, Lx																	+				+											
rhomboidalis, Hos. & Mck						+														+												
salicina, Sap													+								+							+				
Salyorum, Sap													+								+											
spathulata, Wat																		+			+											
sphenobasis, Hos. & Mck						+														+												
straminea, Lx	+																		+													
Sullyi, Newby			+																+													
tæniata, Sap																	+				+											
euryphylla, Hos. & Mck						+														+												
Valdensis, Heer		(?)																	+									+				
viburnifolia, Lx	+																		+													
Victoriæ, Daws											+									+												
Westfalica, Hos. & Mck						+														+				+								
Wilmsii, Hos						+														+												
Dryophyllum, Deb	2			15	1												1	8	2	16	8				+							+
Aquisgranense, Deb				+																+												
Alberti-Magni, Deb				+																+												
Benthianum, Deb				+																+												
campteroneurum, Deb				+																+												
crenatum, Lx	+																		+													
Crepini, Deb				+																+												
cretaceum, Deb				+																+												
curticellense, (Wat.) Sap																	+	+			+											
Dethimusianum, Deb				+																+												

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bruchaux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Dryophyllum, Deb.—Continued.																																
Dewalquei, Sap																		+			+											
Eodrys, Deb				+																+												
exiguum, Deb				+																+												
gracile, Deb				+																+												
Hausmanni, (Dunk.) Sap					+															+												
Heerii, Deb				+																+												
integrum, Sap																		+			+											
laxinerve, Sap																		+			+											
Lerschianum, Deb				+																+												
Lesquereuxianum, Deb				+																+												
lineare, Sap																		+			+											
Palæocastanea, Sap																		+			+											
regaliaquense, Deb				+																+												
subcretaceum, Sap																		+			+											
subfalcatum, Lx	+																		+													
tenuifolium, Deb				+																+												
vittatum, Sap																		+			+											
Pasaniopsis, Sap. & Mar.																	1				1											+
rectinervis, Sap. & Mar																	+				+											
Corylus, L *a*		1	5																5									+	+	+		
Americana, Walt.		{	B. A. +	}															+												+	
grandifolia, Newby			+																+													
Mac Quarrii (Forbes) Heer		+	+																+								+	+				
orbiculata, Newby			+																+													
rostrata, Ait		{	B. A. +	}															+												+	
Ostrya, Scop *b*														1							1					+	+	+				
humilis, Sap														+							+											

a (7) Temperate Northern Hemisphere, Europe, Asia, North America.

b (2) Temperate Northern Hemisphere, Europe, Asia, North America.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Carpinus, L *a*																		2			2					+		+	+	+		
Lebrunii, Wat.																		+			+											
Suessionensis, Wat.																		+			+											
Carpinites, Göpp									1											1												+
microphylla, Heer									+											+												
Alnus, Gærtn *b*		1	2						1					1			2	3	2	1	6					+	+	+	+			
antiquorum, Sap.														+							+											
cardiophylla, Sap.																		+			+											
Kefersteinii, Göpp		+	(?)																+							+	+	+				
Mülleri, Ett.																	+				+											
præcursor (Gey.) Ett.																	+				+											
propinqua, Wat.																		+			+											
protogæa, Heer									+											+												
serrata, Newby			+																+													
trinervis, Wat.																		+			+											
Alnites, Göpp											1									1												+
insignis, Daws											+									+												
Betula, L *c*	1	2							3	1	1		1				1	3	3	5	5					+	+	+		+		
atavina, Heer									+											+												
Daltoniana, Ett.																	+				+											
Gœpperti, Lx		+																	+													
gracilis, Ludw	+																		+									+				
gypsicola, Sap													+								+											
ostryæfolia, Sap.																		+			+											
perantiqua, Daws.											+									+												
Sezannensis, Wat.																		+			+											
Stevensoni, Lx		+																	+													
Suessionensis, Wat.																		+			+											
tremula, Heer									+											+												
vetusta, Heer									+											+												

a (9) Temperate Northern Hemisphere, Europe, Asia, North America.

b (14) Europe, Middle and Northern Asia, North America, Andes (1 South Africa?).

c (25) Europe, Middle and Northern Asia, North America.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.											
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Betula, L.—Continued.																																
species, Daws										+										+												
Myricaceæ:																																
Myrica, L. (Comptonia, Banks) *a*	2				2	2			3			2	11	1		6	7	10	2	7	36			+	+	+	+	+		+		
æmula, Heer																	+				+											
aculeata, Sap													+								+											
angustata, Schp													+								+											
angustissima, Wat																		+			+											
apiculata, Sap																		+			+											
Aquensis, Sap													+								+											
arguta, Sap													+								+											
attenuata, Wat																		+			+											
banksiæfolia, Ung																+					+						+	+				
concisa, Wat																		+			+											
crenulata, Sap																	+				+											
crenulata (Heer) Schp																	+				+											
cretacea, Heer					+															+												
dilleniæfolia, Schp																+					+						+					
Germari, Heer																	+				+							+				
gracilis, Sap													+								+											
Hæringiana, Ung																+					+						+					
hakeæfolia (Ung.) Sap																+					+						+	+				
ilicifolia, Sap													+								+											
lævigata (Heer) Sap																	+				+						+	+				
leiophylla, Hos. & Mck						+														+												
Lessigii, Lx	+																		+	+												
longa, Heer									+											+				+								
longifolia, Ung																+					+						+	+				
magnifica, Wat																		+			+											
Marceauxi, Wat																		+			+											

a (35) Temperate and warmer regions of the world, except Australia.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Myrica, L. (Comptonia, Banks)—Continued.																																
Matheroniana, Sap													+								+						+					
Meissneri (Heer) Schp																	+				+											
Meneghinii, Ung																	+				+											
palæocerifera, Sap													+								+											
parvula, Heer									+											+												
pedunculata, Wat																		+			+											
platyphylla, Sap																		+			+											
præcox, Heer									+											+												
primæva, Hos. & Mck						+														+												
pseudodrymeja, Sap													+								+											
salicina, Ung																+					+						+	+				
Saportana, Schp													+								+											
Schenkiana, Heer					+															+												
sinuata, Sap													+								+											
subhæringiana, Sap												+									+											
subincisa, Sap																		+			+											
Suessionensis, Wat																		+			+											
Torreyi, Lx	+																		+													
Vinayi, Sap												+		+							+											
Juglandaceæ:																																
Juglans, L *a*	4	4	6						1		1						2		8	2	2			+	+	+	+	+	+	+		
appressa, Lx																	+				+											
(?) cinerea, L			B.A.																+												+	
crassipes, Heer									+											+				+								
denticulata, Heer		+	(?)																+	+						+		+				
Harwoodensis, Daws											+									+												
Leconteana, Lx	+	+																	+													

a (8) Temperate and subtropical Northern Hemisphere; 1 Europe and Middle Asia; 2 Eastern Asia and Japan; 4 or 5 North America, Canada, and California, to West Indies and Mexico.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.							Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Juglans, L—Continued.																																
nigella, Heer			+																+													
rhamnoides, Lx	+	+	+																+													
rugosa, Lx	+	+	+																+													
Saffordiana, Lx																	+				+											
Schimperi, Lx	+																		+							+						
Woodiana, Heer			+																+													
Juglandites, St				1														3		1	3											+
cernuus, Sap																		+			+											
elegans, Göpp				+																+												
olmediæformis, Sap																		+			+											
peramplus, Sap																		+			+											
Carya, Nutt *a*		1	1														1		1		1					+	+	+	+			
antiquorum, Newby		+	B. A. +																+													
Heerii, Ett																	+				+							+				
Palæocarya, Sap													1								1											+
atavia, Sap													+								+											
Platanaceæ:																																
Platanus, L *b*	2	2	6						2										8	2				+	+			+	+			
aceroides, Göpp		+	+																+									+				
affinis, Lx									+											+				+	+							
Guillelmæ, Göpp		+	+																+									+				
Haydeni, Newby			+																+													
heterophylla, Newby			B. A. +																+													
Newberryana, Heer									+											+					+							
nobilis, Newby			B. A. +																+													
Raynoldsii, Newby			+																+													

a (10) North America (1 Mexico).

b (6) Temperate and subtropical Northern Hemisphere; 2 Eastern Europe and Asia; 2 America.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Platanus, L.—Continued.																																
Raynoldsii integrifolia, Lx	+																		+													
rhomboidea, Lx	+																		+													
Urticaceæ:																																
Artocarpus, Forst *a*						1														1								+				
undulata, Hos						+														+												
Artocarpoides, Sap *b*																		2			2											+
conocephaloidea, Sap																		+			+											
pouroumæformis, Sap																		+			+											
Artocarpidium, Ung																1	1				2			+			+	+				+
Ephialtæ, Ett																+					+											
Stuarti, Ett																	+				+											
Ficus, L *c*	14	6	6		2	10			2	1	1		4		1	3	10		20	16	18			+	+	+	+	+		+		
angulata, Hos. & Mck						+														+												
angustifolia, Hos						+														+												
arcinervis (Rossm.) Heer																	+				+						+	+				
artica, Heer									+											+												
arenacea, Lx		+	(?)																+							+						
artocarpoides, Lx			+																+													
asarifolia, Ltt	+																		+									+				
atavina, Heer									+											+				+								
auriculata, Lx	+		(?)																+													
cinnamomoides, Lx																	+				+											
crassinervis, Hos						+														+												
cretacea, Hos						+														+												
cuneata, Newby											+									+												
Dalmatica, Ett	+															+			+		+											
densinervis, Hos. & Mck						+														+												

a (40) Tropical Asia, Pacific islands, tropical Africa (?), Ceylon, Malay Archipelago.

b (Artocarpus, cf. Coussapoa 18 and Pourouma 20) Tropical South America.

c (600) Warmer regions of the globe. Most abundant in Malay Archipelago and Pacific islands. Few extra tropical Japan and Mediterranean region. Wanting in North America, except Mexico.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Ficus, L.—Continued.																																
dentata, Hos						+														+												
elongata, Hos						+														+												
Giebeli, Heer																	+				+							+				
gracilis, Hos						+														+												
Haydenii, Lx	+																		+													
Horneri, Heer																	+				+											
irregularis, Lx	+																		+													
Jynx, Ung																+					+						+					
lanceolata, *Heer*			(?)																+							+	+	+				
laurifolia, Hos. & Mek						+														+												
longifolia, Hos						+														+												
maxima, Daws										+										+												
Morloti, Ung																+					+						+	+				
Morrisii, De la Harpe															+						+											
nervosa, Newby		+																	+													
oblanceolata, Lx		+																	+													
obscurata, Sap													+								+											
occidentalis, Lx	+																		+													
planicostata, Lx	+																		+													
planicostata Goldiana, Lx	+																		+													
planicostata latifolia, Lx	+																		+													
platanifolia, Sap													+								+											
pseudopopulus, Lx		+																	+							+						
pulcherrima, Sap													+								+											
Reuschii, Hos					+															+												
Schimperi, Lx																	+				+											
Schlechtendali, Heer																	+				+											
Smithsoniana, Lx	+																		+													
spectabilis, Lx	+		B. A.?																+													
subtruncata, Lx	+																		+													

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Ficus, L.—Continued.																																
tenuifolia, Hos					+															+												
tiliæfolia, Al. Br	+	+	B. A. +														+		+		+						+	+				
tremula, Heer																	+				+											
trilobata, Heer																	+				+											
uncata, Lx	+	+																	+													
venusta, Sap													+								+											
Verbeekiana, Heer																	+				+											
Protoficus, Sap																		4			4											+
crenulata, Sap																		+			+											
insignis, Sap																		+			+											
lacera, Sap																		+			+											
Sezannensis, Sap																		+			+											
Ficonium, Ett																	1				1											+
Solandri, Ett																	+				+											
Planera, Gmel *a*			1						1										1	1						+		+	+			
antiqua, Heer									+											+												
microphylla, Newby			+																+													
Ulmus, L *b*											1	1	2					4		1	7					+	+	+	+	+		
antiquissima, Sap																		+			+											
betulacea, Sap																		+			+											
Brongniartii, Pom												+									+											
dubia, Daws											+									+												
Marioni, Sap													+								+											
modesta, Wat																		+			+											
oppositinervis, Wat																		+			+											
plurinervia, Ung													+								+							+				
Santalaceæ:																																
Leptomeria, R. Br *c*													2								2						+	+				

a (1) Southern United States. *b* (16) Temperate Northern Hemisphere, mountains of tropical Asia. *c* (14) Australia.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Leptomeria, R. Br.—Continued.																																
flexuosa, Ett													+								+						+					
prisca, Sap													+								+											
Osyris, L *a*													1								1											
primæva, Sap													+								+											
Santalum, L *b*																3					3					+	+	+				
Acheronticum, Ett																+					+						+	+				
salicinum, Ett																+					+						+	+				
osyrinum, Ett																+					+						+					
Thymelæaceæ:																																
Pimelea, Banks *c*																	1				1					+	+					
borealis, Heer																	+				+											
Proteaceæ:																																
Dryandra, R. Br *d*												1		1							1							+				
Michloti (Wat.) Sap												+		+							+											
Dryandroides, Ung						2						1					1			2	1			+			+	+				+
Haldemiana, Hos. & Mck						+														+												
microphylla, Hos. & Mck						+														+												
Roginei, Wat												+					+				+											
Banksia, L *e*																	1				1			+			+	+				
Helvetica, Heer																	+				+							+				
Banksites, Sap														3							3					+	+					+
Aquensis, Sap														+							+											
linearis, Sap														+							+											
repertus, Sap														+							+											
Knightia, R. Br *f*																	1				1											
Daltoniana, Ett																	+				+											
Knightites, Sap													1								1						+					+
Gaudini, Sap													+								+											

a (5-6) Southern Europe, Africa (nearly all parts), East Indies.
b (8) East Indies, Malay Archipelago, Australia, Pacific islands.
c (76) Australia and New Zealand.
d (47) Extratropical Western Australia.
e (46) Australia, mostly extratropical.
f (3) 1 New Zealand, 2 New Caledonia.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Embothrites, Ung *a*													2								2						+	+				+
Aquensis, Sap													+								+											
stenopteris, Sap													+								+											
Lomatia, R. Br *b*																2					2				+	+	+	+				
Bolcensis, Ung																+					+											
latior, Heer																+					+						+	+				
Lomatites, Sap													7								7			+			+					+
acerosus, Sap													+								+											
Aquensis, Sap													+								+							+				
Aquensis acuminatus, Sap													+								+											
Aquensis brevior, Sap													+								+											
Aquensis coriaceus, Sap													+								+											
Aquensis intermedius, Sap													+								+											
sinuatus, Sap													+								+											
Grevillea, R. Br. *c*													5				1				6						+	+				
coriacea, Sap													+								+											
elliptica, Sap													+								+											
myrtifolia, Sap													+								+											
nervosa, Heer																	+				+											
provincialis, Sap													+								+											
rigida, Sap													+								+						+					
Persoonia, Sm *d*																	1				1						+	+				
Kunzii, Heer																	+				+											
Adenanthos, Labill. *e*				1																1												
species, Sap				+																+												
Petrophiloides, Bow. *f*															2						2						+					+
imbricatus, Bow															+						+											
Richardsoni, Bow															+						+											

a (Embothrium 4) South America, extratropical or Andes.
b (9) 3 Chile, 6 Australia.
c (160) Australia; 7 New Caledonia.
d (60) Australia, 1 New Zealand.
e (15) Extratropical Western Australia.
f (Petrophila 35) Australia.

Table of distribution of Laramie, Senonian, and Eocene plants—**Continued.**

Species represented.	Laramie: Bitter Creek, Golden, Raton Mountain, &c.	Laramie: Carbon and Evanston.	Laramie: Fort Union group.	Senonian: Aix-la-Chapelle.	Senonian: Harz District.	Senonian: Westphalia.	Senonian: Gosau formation, Austria.	Senonian: Lignites of Fuveau, Provence.	Senonian: Patoot, Greenland.	Senonian: Peace and Pine Rivers, British America.	Senonian: Vancouver and Orcas Islands.	Eocene: Paris Basin.	Eocene: Aix in Provence.	Eocene: Arkoses de Brives.	Eocene: London clay.	Eocene: Mounts Bolca, Pastello, and Promina.	Eocene: Other typical Eocene.	Eocene: Paleocene (Bracheux, Sézanne, Soissons, Gol.)	Summary of the foregoing: Laramie.	Summary of the foregoing: Senonian.	Summary of the foregoing: Eocene.	Other formations in which found: Lower than Cretaceous.	Other formations in which found: Lower Cretaceous (below Cenomanian).	Other formations in which found: Cenomanian.	Other formations in which found: Dakota group.	Other formations in which found: Green River group.	Other formations in which found: Oligocene.	Other formations in which found: Miocene.	Other formations in which found: Pliocene.	Other formations in which found: Quaternary.	Other formations in which found: Living species.	Other formations in which found: Genera extinct.
Proteoides, Heer *a*					2					1										3				+	+							+
ilicoides, Heer					+															+												
lancifolius, Heer					+															+					+							
longus, Heer										+										+				+								
Palæodendron, Sap													2								2						+					+
gypsophilum, Sap													+								+											
longissimum, Sap													+								+											
Leucadendrites, Sap *b*													1								1						+					+
extinctus, Sap													+								+											
Oleraceæ:																																
Oleracites, Sap													2								2											+
Beta prisca, Sap													+								+											
convolvuloides, Sap													+								+											
Laurineæ:																																
Laurus, L *c*	3	2	2			1			3	1			3	1	1	2	5	9	6	5	18			+	+		+	+	+	+		
acuminata, Newby			+																+													
affinis, Hos. & Mck						+														+												
angusta, Heer									+											+				+								
Apollinis, Heer																	+				+											
assimilis, Sap																		+			+											
Australiensis, Ett																	+				+											
Brossiana, Lx	+																		+													
crassinervis, Daws										+										+												
Delessii, Sap																		+			+											
Forbesii, De la Harpe															+		+				+											
Forbesii angustior, Sap														+							+											
gypsorum, Sap													+								+											
Heersiensis, Sap																		+			+											
Hollæ, Heer									+											+												
Lalages, Ung																+	+				+						+	+				

a (Protea 60) Extratropical Africa, 1 or 2 tropical Africa.

b (Leucadendron 70) South Africa.

c (2) 1 Mediterranean region, 1 Canary Islands.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Laurus, L.—Continued.																																
latior, Sap																		+			+											
neglecta, Sap																		+			+											
ocoteoides, Lx	+																		+													
Omalii, Sap																		+			+											
pachyphylla, Ett																+					+											
Plutonia, Heer									+											+				+								
præstans, Lx	+																		+													
primigenia, Ung		+	(?)										+				+		+		+						+	+				
protodaphne, Sap													+								+											
socialis, Lx		+																	+													
subprimigenia, Sap																		+			+											
tetrantheracea, Schp																		+			+											
vetusta Sap																		+			+											
Laurophyllum, Göpp										1										1												+
debile, Daws										+										+												
Lindera, Thunb. (Benzoin, Nees) *a*																		1			1						+	+	+			
neglecta, Sap. sp																		+			+											
Litsæa, Lam. (including Tetranthera, Jacq.) *b*		1	1			1											1	1	2	1	2						+	+				
Bœttgeri, Gey																	+				+											
elatinervis, Sap. & Mar																		+			+											
laurinoides, Hos. & Mck						+														+												
præcursoria, Lx. sp			+																+													
sessiliflora, Lx. sp		+																	+													
Sassafras, Nees *c*			1						1		1						1	1	1	2	2			+	+		+	+	+			
Germanicum, Heer																	+				+											
Pfaffianum, Heer									+											+												

a (50) Tropical and Eastern Asia, Japan, North America.

b (140) Tropical and Eastern Asia, Japan, Malay Archipelago, tropical and subtropical Australia, New Zealand, New Caledonia.

c (1) North America.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.											
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Sassafras, Nees.—Continued.																																
primigenium, Sap																		+			+											
Selwynii, Daws			B. A.																+													
species, Daws											+									+												
Ocotea, Aubl. (Oreodaphne Nees) *a*						1														1					+			+	+	+		
apicifolia, Sap. & Mar						+														+												
Persea, Gærtn *b*																	2	2			4				+		+	+	+			
lancifolia, Lx																	+				+											
palæomorpha, Sap. & Mar																		+			+											
pedata, Lx																	+				+											
vetusta, Sap																		+			+											
Cinnamomum, Blume *c*	2	3	2						2		1		6			3	3	1	4	3	12			+	+	+	+	+	+			
affine, Lx	+	+																	+									+				
Aquense, Sap													+								+											
camphoræfolium, Sap													+								+											
ellipsoideum, Sap									+											+												
emarginatum, Sap													+								+											
grandifolium (Ett.) Schp																+					+						+					
Heerii, Lx											+									+					+							
lanceolatum (Ung.) Heer		+											+			+			+		+						+	+				
Leichardtii, Ett																	+				+											
Mississippiense, Lx																	+				+											
ovale, Sap													+								+											
polymorphum, Al. Br	+		(?)													+			+		+						+	+				
polymorphoides, McCoy																	+				+											
Scheuchzeri, Heer		+	(?)																+						+	+	+	+				
Sextianum, Sap													+								+											
Sezannense, Wat									+									+		+	+											
Daphnogene, Ung. emend	1												3		2		1	3	1		7			+			+	+				+

a (200) Tropical and subtropical America; few in Canary Islands, South Africa, and Mascarene Islands.

b (100) Tropical and subtropical Asia, tropical and extra-tropical America, Virginia, Chile; 1 Canary Islands.

c (50) Tropical and subtropical Asia, Japan, tropical Australia.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Daphnogene, Ung. emend—Continued.																																
Anglica, Heer	+														+				+		+											
coriacea, Sap													+								+											
elegans, Wat																		+			+											
longinqua, Sap																		+			+											
parvula, Sap													+								+											
Raincourtii, Sap																		+			+											
Veronensis, M													+		+		+				+											
Monimiaceæ:																																
Monimiopsis, Sap *a*																		3			3											+
abscondita, Sap																		+			+											
amboræfolia, Sap																		+			+											
fraterna, Sap																		+			+											
Aristolochiaceæ:																																
Aristolochia, L *b*			1																1						+			+				
cordifolia, Newby			+																+													
Polygonaceæ:																																
Coccoloba, L *c*		1																	1									+				
lævigata, Lx		+																	+													
Nyctagineæ:																																
Pisonia, L *d*	1															1			1		1						+	+				
eocenica, Ett																+					+						+	+				
racemosa, Lx	+																		+													
Division II.—Polypetalæ.																																
Cornaceæ:																																
Nyssa, L *e*	1		1																1									+				
lanceolata, Lx	+		(?)																+													

a (Monimia 3) Mascarene Islands. *b* (180) Warmer and temperate regions of the whole globe. *c* (80) America, chiefly tropical; few in Mexico and Florida. *d* (60) Tropical America; few in Asia, Pacific and Mascarene Islands. *e* (5–6) Temperate and warm Eastern North America, Eastern Himalayas, Malay Archipelago.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Cornus, L *a*	3	1	1						2				1					1	4	2	2			+			+	+		+		
confusa, Sap													+								+											
Holmiana, Heer									+											+												
Nebrascensis, Schp			+																+													
platyphylla, Sap																		+			+											
rhamnifolia, Web	+																		+									+				
Studeri, Heer	+	+																	+								+	+				
suborbifera, Lx	+																		+													
Thulensis, Heer									+											+												
Araliaceæ:																																
Hedera, L *b*									1				1					1		1	2			+	+	+	+	+	+	+		
cuneata, Heer									+											+				+								
Philiberti, Sap													+								+											
prisca, Sap																		+			+											
Cussonia, Thunb *c*													2								2							+				
rediviva, Sap													+								+											
rectinervis, Sap													+								+											
Panax, L *d*									2											2				+			+	+				
globulifera, Heer									+											+												
macrocarpa, Heer									+											+												
Aralia, L *e*	1		3			2			1				7		1	1		9	4	3	17			+	+	+	+	+				
acerifolia, Lx			+																+									+				
argutidens, Sap																		+			+											
bicornis, Sap													+								+											
calyptrocarpa, Sap													+								+											
cordifolia, Sap																		+			+											
crenata, Sap																		+			+											

a (25) Europe, Asia, temperate America; few in Mexico; 1 Peru.
b (2) 1 temperate and subtropical Northern Hemisphere from Canaries to Japan; 1 Australia.
c (11) Tropical and Southern Africa, Mascarene Islands.
d (25) Tropical and Eastern Asia to Mantchooria, tropical Africa, Pacific Islands, New Zealand, Australia.
e (30) Tropical and Eastern temperate Asia, North America, Mexico, Japan, Malay Archipelago.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Aralia, L.—Continued.																																
demersa, Sap																		+			+											
denticulata, Hos, & Mck						+														+												
hederacea, Sap																		+			+											
Looziana, Sap. & Mar																		+			+											
microphylla, Hos, & Mck						+														+												
multifida, Sap													+								+											
notata, Lx				+															+													
primigenia (De la Harpe) Heer															+	+					+						+					
pungens, Lx	+																		+													
racemifera, Sap													+								+											
redux, Sap													+								+											
robusta, Sap																		+			+											
Sezannensis, Sap																		+			+											
spinulosa, Sap													+								+											
triloba, Newby			+																+													
tripartita, Sap													+								+											
venulosa, Sap																		+			+											
Waigattensis, Heer									+											+												
Onagrarieæ:																																
Trapa, L *a*	1		1																2									+				
microphylla, Lx	+																		+													
borealis, Heer			B. A.																+									+				
Melastomaceæ:																																
Melastomites, Ung *b*						1														1							+	+				+
cuneiformis, Hos. & Mck						+														+												
Myrtaceæ:																																
Eugenia, L *c*																1	1				2						+	+				
Apollinis, Ung																+					+						+	+				
Hollæ, Ung																	+				+											

a (2–3) Middle and Eastern Europe, tropical and subtropical Asia and Africa.

b (Melastoma, 40) Tropical Asia, Northern Australia, Oceanica, 1 Seychelles.

c (700) Tropical and subtropical America, tropical Asia; few Australia and Africa.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bruchenx, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Myrtus L *a*													3								3						+	+		+		
Aquensis, Sap													+								+											
corrugata, Sap													+								+											
rugosa, Sap													+								+											
Myrtophyllum, Heer					1	1												1		2	1			+								+
? cryptoneuron, Sap. & Mar						+												+		+	+											
pusillum, Heer					+															+												
Metrosideros, Banks *b*																	1				1			+			+	+				
Saxonum, Heer																	+				+											
Eucalyptus, L'Her *c*	1					2										1	3		1	2	3			+		+	+	+				
Haldemiana, Deb						+														+												
Delftii, Ett																	+				+											
Hæringiana, Ett	+																		+								+	+				
inæquilatera, Marck						+														+												
oceanica, Ung																+	+				+						+	+				
Verbeeki, Heer																	+				+											
Callistemophyllum, Ett *d*													1			2	1				4			+			+	+				+
diosmoides, Ett																+					+											
Giebeli, Heer																	+				+											
melaleucæforme, Ett																+					+						+	+				
priscum, Sap													+								+											
Leptospermites, Sap *e*													1								1											+
repertus, Sap													+								+											
Combretaceæ:																																
Terminalia, L *f*													2								2						+	+				
elegans, Heer													+								+											

a (100) Extratropical Western South America, tropical America (fewer); 8 Australia, 4 New Zealand, 1 Southern Europe and Western Asia.
b (18) Pacific Islands (New Zealand—Hawaii); 1 tropical Australia, 1 Indian Archipelago, 1 South Africa.
c (100) Australia, Indian Archipelago (few).
d (Callistemon 12) Australia; 1 or 2 New Caledonia.
e (Leptospermum 25) *Australia*; New Zealand, New Caledonia, Indian Archipelago (few).
f (80–90) Tropical Eastern Hemisphere, few tropical America.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Monts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Terminalia, L.—Continued.																																
gypsorum, Sap													+								+											
Hamamelideæ:																																
Liquidambar, L *a*																		1			1				+	+		+	+	+		
Gœpperti, Wat																		+			+											
Hamamelites, Sap *b*																		1			1				+							+
fothergilloides, Sap																		+			+											
Saxifrageæ:																																
Ribes, L *c*													1								1											
Celtorum, Sap													+								+											
Ceratopetalum, Sm *d*															1		1				1						+	+				
myricinum, De la Harpe															+		+				+						+					
Rosaceæ:																																
Amelanchier, Lindl *e*			1																1							+		+				
similis, Newby			+																+													
Cotoneaster, Medik *f*													7								7						+	+				
assimilanda, Sap													+								+											
major, Sap													+								+											
minuta, Sap													+								+											
obscurata, Sap													+								+											
primordialis, Sap													+								+											
protogæa, Sap													+								+											
socia, Sap													+								+											
Cratægus, L *g*		1							2				1						1	2	1					+	+	+	+	+		
æquidentata, Lx		+																	+													
atavina, Heer									+											+												

a (2) 1 tropical to temperate North America, 1 Asia Minor.
b (Hamamelis 2) 1 Eastern North America, 1 Japan.
c (56) Temperate Europe, Asia and America; Andes.
d (2) Temperate Eastern Australia.
e (4) Asia Minor, Japan, North America.
f (15) Europe, Northern Africa, Middle and Western Asia, Siberia, mountains of the East Indies, Mexico.
g (65) Europe, Western and Northern Asia, Japan, North America (Canada to Mexico); 1 Andes, New Grenada.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Cratægus, L.—Continued.																																
fragarioides, Heer									+											+												
nobilis, Sap													+								+											
Leguminosæ:																																
Acacia, Willd *a*													9	1							10					+	+	+				
ambigua, Sap													+								+											
Aquensis, Sap													+								+											
brevior, Sap													+								+											
Corsacensis, Sap														+							+											
julibrizoides, Sap													+								+											
lacerata, Sap													+								+											
longinqua, Sap													+								+											
pleiasperma, Sap													+								+											
poincianoides, Sap													+								+											
seminifera, Sap													+								+											
Mimosa, L *b*													1								1						+	+				
deperdita, Sap													+								+											
Cercis, L *c*			2										1						2		1					+	+	+	+	+		
antiqua, Sap													+								+											
borealis, Newby			+																+													
truncata, Lx			+																+													
Podogonium, Heer	1																		1							+	+	+				+
Americanum, Lx	+																		+							+						
Cassia, L *d*		1							1							4	2		1	1	6			+		+	+	+				
ambigua, Ung																+					+						+	+				
australis, Heer																	+				+											
concinna, Heer		+																	+									+				
Cookii, Ett																	+				+											

a (420) Africa (chiefly), Australia, and other warm regions.
b (230) America (warmer regions), Africa and Asia (few).
c (3-4) Europe, temperate Asia, Japan, North America.
d (400) Warm regions Bonaria and Chile to Mexico, Eastern United States, Africa (all parts), tropical Asia, Australia (not in New Zealand nor Tasmania).

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Monts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Cassia, L.—Continued.																																
Dioneus, Ett.																+					+							+				
Ettingshauseni, Heer									+											+				+								
hyperborea, Ung.																+					+						+	+				
Phaseolites, Ung.																+					+						+	+				
Cæsalpinia, L *a*															1	2					3						+	+				
æmula, Heer															+						+											
Haidingeri, Ett.																+					+						+	+				
Norica, Ung																+					+						+	+				
Cæsalpinites, Sap.													6								6						+	+				+
cassiæformis, Sap.													+								+											
depressus, Sap.													+								+											
gracilis, Sap													+								+											
latifolius, Sap.													+								+											
obscurus, Sap.													+								+											
proximus, Sap.													+								+											
Sophora, L *b*													1	1		1					3						+	+				
assimilis, Sap													+								+											
brevissima, Sap.														+							+											
Europæa, Ung.																+					+						+	+				
Pongamia, Vent *c*																1					1											
protogæa, M																+					+											
Drepanocarpus, Mey *d*																1					1						+	+				
Decampii, M																+					+											
Dalbergia, Linn. f *e*																2	3				5			+		+	+	+				
Diemenii, Ett.																	+				+											
Junghuhniana, Heer																	+				+											
Pastellina, M																+					+											
primæva, Ung.																+					+						+	+				

a (38) Warmer regions of both hemispheres.
b (22) Warmer regions of both hemispheres.
c (1) Tropical Asia and Australia.
d (8) Tropical America; 1 tropical Africa.
e (64) Tropical America, Africa, Asia; 2 Australia.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Dalbergia, Linn. f—Continued.																																
pumilio, Heer																	+				+											
Micropodium, Sap													2								2											+
affine, Sap													+								+											
oligospermum, Sap													+								+											
Phaseolites, Ung *a*													2			1					3						+	+				+
clitoriæformis, Sap													+								+											
obconicus, Sap													+								+											
orbicularis, Ung																+					+						+	+				
Ervites, Sap *b*													1								1						+					+
primævus, Sap													+								+											
Colutea, L *c*									1				1							1	1			+				+				
parcæfoliata, Sap													+								+											
protogæa, Heer									+											+												
Leguminosites, Brongn		1	1						4		1			1	1		3		2	5	4			+	+	+	+	+				+
arachioides, Lx		+																	+													
cassioides, Lx			(?)																+							+						
dentatus, Heer									+											+												
frigidus, Heer									+											+												
gastrolobianus, Sap														+							+											
Kennedyi, Ett																	+				+											
orbiculatus, Heer									+											+				+				+				
Patootensis, Heer									+											+												
Sprengeli, Heer																	+				+											
species (fructus, etc.)											+				+		+			+	+											
Faboidea, Bow															25						25											+
25 species															+						+											
Anacardiaceæ:																																
Pistacia, L *d*													1								1						+	+				

a (Phaseolus 60) Warmer regions (including temperate North America).
b (Vicia 180) Temperate Northern Hemisphere and South America.
c (7–8) Middle and Southern Europe, temperate and subtropical Asia.
d (6) Mediterranean region, Canary Islands, warmer Western Asia, Mexico.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
Species represented.	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Monts Bolca, Pastello and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous, (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Pistacia, L.—Continued.																																
Aquensis, Sap													+								+											
Rhus, L *a*	2	1	2		1								8				1		5	1	9			+		+	+	+		+		
abbreviata, Sap													+								+											
adscripta, Sap													+								+											
bidens, Heer																	+				+											
Blitum, Sap													+								+											
cretacea, Heer					+															+												
distracta, Sap													+								+											
Evansii, Lx		+																	+							+						
membranacea, Lx	+																		+													
minutissima, Sap													+								+											
nervosa, Newby			+																+													
palæophylla, Sap													+								+											
Meriani, Lx	+																		+													
reddita, Sap													+								+											
rhomboidalis, Sap													+								+											
Winchellii, Lx			+																+													
Anacardites, Sap *b*								1												1				+			+	+				+
alnifolius, Sap								+												+												
Trilobium, Sap													1								1											
Ungeri, Sap													+								+											
Sapindaceæ:																																
Negundo, Mœnch *c*			1																1					+	+			+				
triloba, Newby			+																+													
Acer, L *d*		1	2						2				2						3	2	2					+	+	+	+	+		
ampelophyllum, Sap													+								+											
arcticum, Heer			+																+									+				
caudatum, Heer									+											+												

a (120) Cape Colony (most numerous); warmer extratropical regions of both hemispheres; few tropical.

b (Anacardium 6) Tropical America.

c (2-4) Temperate North America, Japan.

d (50) Europe, North America, Northern Asia.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Acer L.—Continued.																																
edentatum, Heer									+											+												
gracilescens, Lx			+																+													
Sextianum, Sap													+								+											
trilobatum productum, Lx		+																	+													
Sapindus, L *a*	1		3						1				1	1			3		4	1	5			+	+	+	+	+				
æmulus, Heer																	+				+											
anceps, Heer																	+				+											
affinis, Newby		{	B. A. +	}															+													
caudatus, Lx	+																		+													
drepanophyllus, Sap													+								+											
membranaceus, Newby			+																+													
Morisoni, Heer									+											+				+								
obtusifolius, Lx			+																+							+						
undulatus, Al. Br																	+				+							+				
Vellavensis, Sap														+							+											
Cupanioides, Bow *b*															8						8											+
corrugatus, Bow															+						+											
depressus, Bow															+						+											
grandis, Bow															+						+											
inflatus, Bow															+						+											
lobatus, Bow															+						+											
pygmæus, Bow															+						+											
subangulatus, Bow															+						+											
tumidus, Bow															+						+											
Æsculus, L *c*			1																1									+	+			
antiqua, Daws			B. A.																+													

a (40) Tropical regions of both hemispheres; subtropical, more rare.
b (Cupania 30) Tropical regions of both hemispheres; rarest in Africa.
c (14) North America, Mexico, mountains of New Granada, Himalayas, Persia, Malay Peninsula.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Ampelideæ:																																
Vitis, L. (including Cissus, L.) *a*	5	1																3	5		3					+	+	+	+	+		
ampelopsidea, Sap																		+			+											
lævigata, Lx	+																		+													
lobato-crenata, Lx	+																		+													
Olriki, Heer	+	+																	+									+				
primæva, Sap																		+			+											
Sezannensis, Sap																		+			+											
sparsa, Lx	+																		+													
tricuspidata, Heer	+																		+									+				
Cissites, Heer																		1			1			+	+							+
lacerus, Sap																		+			+											
Chondrophyllum, Bronn					1															1				+								+
hederæforme, Heer					+															+												
Rhamneæ:																																
Pomaderrites, Ett *b*																	1				1											+
Banksii, Ett																	+				+											
Ceanothus, L *c*						1			1		1									3								+				
cretaceus, Daws											+									+												
prodromus, Heer									+											+												
species? Hos. & Mck						+														+												
Rhamnus, L *d*	10	3	3			1			1							1	1	1	12	2	3			+	+	+	+	+		+		
alaternoides, Heer	+																		+									+				
argutidens, Sap																		+			+											
Cleburni, Lx	+																		+													
deformatus, Lx	+																		+													
discolor, Lx	+																		+													
Goldianus, Lx	+	+																	+													

a (230) Tropical, subtropical, and temperate regions; rarest in America.
b (Pomaderris, 16) Southern and Eastern Australia, New Zealand.
c (28) Tropical and temperate North America, especially westward.
d (60) Warm and temperate Europe, Asia, and America (rarer in tropics); tropical Africa, Australia, Pacific islands.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.							Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Rhamnus, L.—Continued.																																
inæqualis, Lx	+																		+													
marginatus, Lx																	+				+											
obovatus, Lx	+	+																	+													
parvifolius, Newby			+																+													
Pfaffianus, Heer									+											+												
rectinervis, Heer	+	+	(?)																+									+				
Rœsleri, Ett																+					+											
Rossmässleri, Ung	+																		+									+				
salicifolius, Lx	+																		+													
species, Hos. & Mck						+														+												
species, Daws			B. A.																+													
Rhamnites, Newby			2																2													+
concinnus, Newby		{	B. A. +	}															+													
elegans, Newby			+																+													
Berchemia, Neck *a*	1																		1								+	+				
multinervis, Al. Br	+																		+									+				
Zizyphus, Juss *b*	3	2							1			1	1		2	2	1	2	5	1	8					+	+	+	+			
Beckwithii, Lx	+																		+													
distortus, Lx	+																		+													
fibrillosus, Lx	+																		+													
Grœnlandicus, Heer									+											+												
hyperboreus, Heer		+																	+													
integrifolius, Heer															+						+											
Meekii, Lx		+																	+													
Meigsii (Lx.), Schp																	+				+											
paradisiacus, Heer													+			+					+											
pseudo-Ungeri, Sap												+									+											

a (10) Northern India, Java, China, eastern tropical Africa, tropical and temperate North America.

b (50) Tropical Asia and America, Africa (rarer), Australia (very rare); warm, extratropical regions of both Hemispheres.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Zizyphus, Juss.—Continued.																																
Raincourtii, Sap																		+			+											
remotidens, Sap																		+			+											
Ungeri, Heer																+					+						+	+				
vetustus, Heer															+						+											
Paliurus, Juss *a*	1	1							1				1						2	1	1				+	+	+	+				
affinis, Heer									+											+												
Colombi, Heer		+																	+									+				
tenuifolius, Heer													+								+							+				
zizyphoides, Lx	+																		+													
Celastrineæ:																																
Celastrus, L *b*									1				2			3				1	5					+	+	+				
Andromedæ, Ung																+					+						+	+				
arctica, Heer									+											+	+											
banksiæformis, Sap													+								+											
oreophilus, Ung																+					+						+	+				
Phlegethontis, Ett																+					+											
pseudo-Bruckmanni, Sap													+								+											
Celastrinites, Sap	1		1															4	2		4					+						+
artocarpoides, Lx	+																		+													
fallax, Sap																		+			+											
Hartogianus, Sap																		+			+											
lævigatus, Lx			(?)																+													
legitimus, Sap																		+			+											
venulosus, Sap																		+			+											
Celastrophyllum, Ett						1			3								1	3		3	4			+			+	+				+
Benedeni, Sap																		+			+											
crenatum, Heer									+											+												
Cunninghami, Ett																	+				+											
lanceolatum, Hos						+			+											+												

a (2) 1 Southern Europe and Western Asia; 1 Southern China.

b (18) Mountains of India, China, Japan; few in North America and Australia; 1 Madagascar.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Celastrophyllum, Ett.—Continued.																																
repandum, Sap																		+			+											
reticulatum, Sap																		+			+											
serratum, Sap									+											+												
Ilicineæ:																																
Ilex, L *a*			2						2				2			1			2	2	3			+	+	+	+	+	+			
borealis, Heer									+											+												
dissimilis, Lx			(?)																+													
microphylla, Newby			+																+													
Patootensis, Heer									+											+												
quercina, Sap													+								+											
Salyorum, Sap													+								+											
stenophylla, Ung																+					+							+				
Simarubeæ:																																
Ailanthus, Desf *b*													4								4					+	+	+				
lancea, Sap													+								+											
minutissima, Sap													+								+											
prisca, Sap													+								+											
recognita, Sap													+								+											
Zygophylleæ:																																
Guajacites, M *c*																2					2											+
enervis, M																+					+											
Heerii, M																+					+											
Malpighiaceæ:																																
Malpighiastrum Ung. *d*																1					1						+	+				+
Dalmaticum, Ett																+					+											
Tiliaceæ:																																
Apeibopsis, Heer *e*	1														1				1		1			+				+				+

a (145) Temperate and tropical regions, chiefly South American; rarest in Africa and Australia.
b (3) East Indies and China.
c (Guaiacum 8) Tropical and subtropical North America.
d (Malpighia 20) Tropical America.
e (Apeiba 5) Tropical America.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.							Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Apeibopsis, Heer.—Continued.																																
discolor, Lx	+																		+													
Symondsii, De la Harpe															+						+											
Tilia, L *a*			1																1							+		+	+	+		
antiqua, Newby			+																+													
Grewiopsis, Sap *b*	2																	6	2		6				+							+
anisomera, Sap																		+			+											
Cleburni, Lx	+																		+													
credneriæformis, Sap																		+			+											
orbiculata, Sap																		+			+											
Saportana, Lx	+																		+													
sidæfolia, Sap																		+			+											
tiliacea, Sap																		+			+											
tremulæfolia, Sap																		+			+											
Sterculiaceæ:																																
Dombeyopsis, Ung *c*	3		1													13	1		4		14						+	+				+
affinis, M																+					+											
auriculata, M																+					+											
Bolcensis, M																+					+											
ceanothifolia, M																+					+											
coccolobæfolia, M																+					+											
deformis, M																+					+											
Granadilla, M																+					+											
grandifolia, Ung	+															+			+		+						+	+				
hibiscifolia, M																+					+											
incerta, M																+					+											
kleinhoviæfolia, M																+					+											
obtusa, Lx	+																		+													
Padangiana, Heer																	+				+											
platanoides, Lx			(?)																+													

a (8) North temperate zone. *b* (Grewia 60) Warmer regions of the Old World. *c* (Dombeya 24) Africa and Mascarene Islands.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Dombeyopsis, Ung.—Continued.																																
sublobata, M.																+					+											
tilioides, M.																+					+											
trivialis, Lx	+																		+													
Pterospermites, Heer *a*																		1			1			+			+	+				+
inæqualis, Sap.																		+			+											
Sterculia, L *b*	1								1				1			1	1	4	1	1	5				+	+	+	+	+			
labrusca, Ung																+	+	+			+						+	+				
Michloti (Wat.) Sap																		+			+											
modesta, Sap.	+																	+	+		+											
tenuiloba, Sap.													+								+											
variabilis, Sap.									+									+		+	+											
Fracastoria, M.																15					15											+
anguria, M.																+					+											
celtriformis, M.																+					+											
Citrullus, M.																+					+											
clavæformis, M.																+					+											
cucurbitina, M.																+					+											
gastrioides, M.																+					+											
gigantea, M.																+					+											
Lagenaria, M.																+					+											
Megapepo, M.																+					+											
Melo, M.																+					+											
pomiformis, M.																+					+											
pyramidalis, M.																+					+											
pyriformis, M.																+					+											
rotunda, M.																+					+											
Zignoana, M.																+					+											
Credneriaceæ:																																
Credneria, Zenk.					6	5														8				+								+

a (Pterospermum 11) Tropical Asia.

b (60) Warmer regions of the globe, chiefly tropical Asia.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Credneria, Zenk.—Continued.																																
acuminata, Hampe					+															+												
denticulata, Zenk					+	+														+												
integerrima, Zenk					+															+				+								
oblonga, Schp					+															+												
subtriloba, Zenk					+	+														+												
tenuinervis, Hos						+														+												
triacuminata, Hampe					+	+														+												
Westfalica, Hos						+														+												
Protophyllum, Lx										3	1									4					+							+
boreale, Daws										+										+												
Leconteanum, Lx										+										+					+							
Nanaimo, Daws											+									+												
rugosum, Lx										+										+					+							
Anisophyllum, Lx											1									1					+							+
species, Daws											+									+												
Malvaceæ:																																
Bombax, L *a*													1				2				3						+	+				
Heerii, Ett																	+				+											
Mitchellii, Ett																	+				+											
sepultiflorum, Sap													+								+											
Ternstrœmiaceæ:																																
Saurauja. Willd *b*																		1			1							+				
robusta, Sap																		+			+											
Pittosporeæ:																																
Pittosporum, Banks *c*													4				1				5						+	+				
Fenzlii, Ett													+								+						+	+				
latifolium, Sap													+								+											
laurinum, Sap													+								+							+				

a (10) Tropical America; 1 tropical Africa, 1 tropical Asia.
b (60) Tropical and subtropical Asia and America.
c (50) Africa, warmer parts of Asia; Pacific Islands, Australia, New Zealand.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Pittosporum, Banks—Continued.																																
priscum, Ett																	+				+											
pulchrum, Sap													+								+											
Nymphæaceæ:																																
Nelumbium, Juss *a*	2															2			2		2			+			+	+				
Buchii, Ett																+					+							+				
Lakesii, Lx	+																		+													
nymphæoides, Ett																+					+											
tenuifolium, Lx	+																		+													
Nymphæa, L *b*													2			1					3						+	+				
Charpentieri, Heer																+					+							+				
gypsorum, Sap													+								+							+				
parvula, Sap													+								+											
Nymphæites, St												1						1			1						+	+				+
arethusæ (Brongn.) St												+						+			+											
Peltophyllum, M																1					1											+
nelumbioides, M																+					+											
Menispermaceæ:																																
Menispermites, Lx *c*											1									1				+	+							+
reniformis, Daws											+									+												
Cocculus, DC *d*																		2			2											
Dumonti, Sap																		+			+											
Kanii, Sap																		+			+											
Macclintockia, Heer									1											1				+				+				+
cretacea, Heer									+											+				+								
Anonaceæ:																																
Anona, L *e*	1																	2	1		2				+			+				
Altenburgensis, Ung																		+			+							+				

a (2) America, Asia, tropical Australia.
b (20) Tropics and Northern Hemisphere, few South Africa and Australia.
c (Menispermum 2) 1 North America, 1 temperate Eastern Asia.
d (10) Tropical Africa and Asia; China; 2 warmer parts of North America.
e (50) Tropical America; 2–3 tropical Africa and Asia.

Table of distribution of Laramie, Senonian, and Eocene plants — Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Anona, L.—Continued.																																
lignitum, Ung																		+			+							+				
robusta, Lx	+																		+													
Asimina, Adans *a*		1															1		1		1							+				
eocenica, Lx		+																	+													
leiocarpa, Lx																	+				+											
Magnoliaceæ:																																
Liriodendron, L *b*									1											1				+	+			+	+			
Meekii, Heer									+											+				+	+							
Magnolia, L *c*	6		1							2				1			7	1	6	2	9			+	+		+	+	+			
angustifolia, Newby	+																		+													
attenuata, Web	+																		+									+				
Brownii, Ett																	+				+											
cordifolia, Lx																	+				+											
Hilgardiana, Lx	+		+														+		+		+											
inæqualis, Sap																		+			+											
laurifolia, Lx																	+				+											
Lesleyana, Lx	+																+		+		+											
Ligerina, Sap														+							+											
magnifica, Daws										+										+												
ovalis, Lx																	+				+											
rotundifolia, Newby	+																		+													
tenuinervis, Lx	+																		+													
tennifolia, Lx										+										+					+							
Torresii, Ett																	+				+											
Ranunculaceæ:																																
Dewalquea, Sap. & Mar						5			1									1		6	1			+								+
Gelindensis, Sap. & Mar						+												+		+	+											
Grœnlandica, Heer									+											+				+								
Haldemiana, Sap. & Mar						+														+												

a (7–8) North America (including Mexico), Central America (Cuba?). *b* (1) North America. *c* (14) North America, Mexico, Japan, China, Himalayas.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Dewalquea, Sap. & Mar.—Continued.																																
Haldemiana angustifolia, Hos. & Mck						+														+												
Haldemiana latifolia, Hos. & Mck						+														+												
insignis, Hos. & Mck						+														+				+								
Division III.—Gamopetalæ.																																
Bignoniaceæ:																																
Catalpa, Juss *a*			1										1						1		1											
crassifolia, Newby			+																+									+				
macrosperma, Sap													+								+											
Solanaceæ:																																
Solanites, Sap													1								1											+
Brongniartii, Sap													+								+											
Convolvulaceæ:																																
Porana, Burm *b*																2					2					+	+	+				
Bolcensis (Ung.) Schp																+					+											
potentilloides (M.) Schp																+					+											
Asclepiadaceæ:																																
Gomphocarpus, R. Br. (including Acerates, Ell.) *c*									1											1				+				+				
arctica, Heer									+											+				+								
Apocynaceæ:																																
Echitonium, Ung *d*																		1			1						+	+				+
Sezannense, Wat																		+			+											
Apocynophyllum, Ung *e*						2										1	3			2	4			+		+	+	+				+
cuneatum, Hos. & Mck						+														+												

a (6) China, Japan, North America, West Indies.
b (6) East Indies, Malay Archipelago, Australia.
c (80) Southern and tropical Africa; Arabia; North and Central America.
d (Echites 35) Tropical America.
e (Apocynum 5) Southern Europe, temperate Asia, North America.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Brabeux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Apocynophyllum, Ung.—Continued.																																
Etheridgii, Ett																	+				+											
neriifolium, Heer																	+				+											
plumeriæfolium, Ett																+					+							+				
subrepandum, Marck						+														+												
Sumatrense, Heer																	+				+											
Nerium, L *a*						1						1	1							1	2						+	+	+			
Parisiense, Sap												+									+											
repertum, Sap													+								+											
Röhlii, Marck						+														+												
Tabernæmontana, L *b*																	1				1							+				
primigenia, Ett																	+				+											
Oleaceæ:																																
Olea, L *c*													1								1					+	+	+				
proxima, Sap													+								+											
Notelæa, Vent *d*																	1				1						+	+				
eocenica, Ett																	+				+						+					
Fraxinus, L *e*	1	1	1						1				1						2	1	1					+		+	+	+		
denticulata, Heer		+	(?)																+									+				
eocenica, Lx	+																		+													
exilis, Sap													+								+											
præcox, Heer									+											+												
Styraceæ:																																
Symplocos, L *f*																		1			1						+	+				
Bureauana, Sap																		+			+											
Ebenaceæ:																																
Diospyros, L *g*	2	1	1						2	1	1		9				2		4	4	11			+	+	+	+	+				

a (2–3) Mediterranean regions, subtropical Asia, Japan.
b (110) Tropical regions of the world.
c (35) Tropical and Middle Asia, Mediterranean region, tropical and South Africa, Mascarene Islands, New Zealand.
d (8) Australia.
e (30) Temperate and subtropical Northern Hemisphere.
f (160) Warmer regions of Asia, Australia, and America (none in Africa).
g (153) Tropical regions of the world; temperate Asia and America.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Diospyros, L.—Continued.																																
adscripta, Sap													+								+											
ambigua, Sap													+								+											
brachysepala, Al. Br.	+																		+							+	+	+				
corrugata, Sap													+								+											
discreta, Sap													+								+											
ficoidea, Lx	+																		+													
Horneri, Heer																	+				+											
involucrans, Sap													+								+											
nitida, Daws										+										+												
oocarpa, Sap													+								+											
præcursor, Sap													+								+											
primæva, Heer									+											+				+	+							
rhododendrifolia, Sap													+								+											
rugosa, Sap													+								+											
Steenstrupi, Heer									+											+												
Vancouveriensis, Daws											+									+												
vetusta, Heer																	+				+											
Wodani, Ung		+																	+									+				
species, Daws			B. A.																+													
Sapotaceæ:																																
Bumelia, Sw *a*													1			2					3					+	+	+				
oblongifolia, Ett																+					+											
Oreadum, Ung																+					+						+	+				
subspathulata, Sap													+								+											
Sapotacites, Ett									4				1			3	2			4	6				+		+	+				+
ambiguus, Ett																+					+						+					
crassipes, Heer																	+				+											
exul, Sap													+								+											
hyperboreus, Heer									+											+												

a (20) Tropical and North America.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Sapotacites, Ett.—Continued.																																
nervillosus, Heer									+											+												
reticulatus, Heer									+								+			+	+											
retusus, Heer									+											+												
sideroxyloides, Ett.																+					+						+	+				
vaccinioides, Ett.																+					+						+					
Myrsineæ:																																
Myrsine, L *a*													6	1			1				8			+		+	+	+				
acuminata, Sap													+								+											
confusa, Sap													+								+											
formosa, Heer																	+				+											
linearis, Sap													+								+											
marginata, Sap													+								+											
recuperata, Sap													+								+											
spinulosa, Sap													+								+											
Vinayana, Sap														+							+											
Ericaceæ:																																
Rhododendron, L *b*																1					1						+	+				
Saturni, Ett																+					+							+				
Andromeda, L *c*		1	1										3			1			1		3			+	+	+		+				
atavia, Sap													+								+											
Grayana, Heer		+	(?)																+									+				
mucronata, Sap													+								+											
protogæa (Ung.) Sap													+			+					+						+	+				
Leucothoe, Don *d*													5								5						+	+				
abbreviata, Sap													+								+											
arcinervis, Sap													+								+											

a (80) Tropical Asia, Africa, and America; a few in Japan, extratropical Africa, Australia, Atlantic islands, and New Zealand.

b (130) Mountains of Europe, Asia, Malay Archipelago, and North America. (Most abundant in the Himalayas.)

c (1) Temperate and subarctic regions of the Northern Hemisphere. (Genus generally made to include Lyonia, Zenobia, and Pieris, ranging to Mexico, West Indies, and Malay peninsula.)

d (8) Eastern North America and Japan.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Leucothoe, Don.—Continued.																																
linearis, Sap													+								+											
pulchra, Sap													+								+											
subterranea, Sap													+								+											
Gaultheria, L *a*																1					1							+				
eocenica, Ett																+					+											
Vacciniaceæ:																																
Vaccinium, L. *b*													6			1					7					+	+	+	+	+		
Acheronticum, Ung																+					+						+	+				
Aquense, Sap													+								+											
obscurum, Sap													+								+											
parvulum, Sap													+								+											
proximum, Sap													+								+											
reticulatum, Al. Br													+								+					+	+	+				
secernendum, Sap													+								+											
Compositæ:																																
Parthenites, Sap *c*													1								1							+				+
priscus, Sap													+								+											
Cypselites, Heer													1								1						+	+				+
gypsorum, Sap													+								+											
Valerianeæ:																																
Valerianellites, Sap *d*													1								1											+
capitatus, Sap													+								+											
Rubiaceæ:																																
Gardenia, L *e*																		1			1							+				
Meriani, Heer																		+			+											

a (90) North America, Andes, mountains of India, and Malay Archipelago; few in Australia and New Zealand, 1 Japan.

b (100) Temperate Northern Hemisphere; mountains of the tropics. (None in south temperate zone.)

c (Parthenium, 6). North and Central America, and West Indies. (Reference very doubtful.)

d (Valerianella, 47). Europe, Northern Africa, Western Asia, and North America. (Most abundant in Mediterranean region.)

e (60) Tropical and subtropical regions of the Old World; Pacific Islands.

Table of distribution of Laramie, Senonian, and Eocene plants—Continued.

Species represented.	Laramie.			Senonian.								Eocene.							Summary of the foregoing.			Other formations in which found.										
	Bitter Creek, Golden, Raton Mountain, &c.	Carbon and Evanston.	Fort Union group.	Aix-la-Chapelle.	Harz District.	Westphalia.	Gosau formation, Austria.	Lignites of Fuveau, Provence.	Patoot, Greenland.	Peace and Pine Rivers, British America.	Vancouver and Orcas Islands.	Paris Basin.	Aix in Provence.	Arkoses de Brives.	London clay.	Mounts Bolca, Pastello, and Promina.	Other typical Eocene.	Paleocene (Bracheux, Sézanne, Soissons, Gel.)	Laramie.	Senonian.	Eocene.	Lower than Cretaceous.	Lower Cretaceous (below Cenomanian).	Cenomanian.	Dakota group.	Green River group.	Oligocene.	Miocene.	Pliocene.	Quaternary.	Living species.	Genera extinct.
Caprifoliaceæ:																																
Viburnum, L *a*	9		7			1			3									2	15	4	2							+	+	+		
anceps, Lx	+																		+													
asperum, Newby			+																+													
attenuatum, Heer									+											+												
Dakotense, Lx			+																+													
Dentoni, Lx			+																+													
dichotomum, Lx	+																		+													
giganteum, Sap																		+			+											
Goldianum, Lx	+																		+													
Lakesii, Lx	+		B. A.																+													
lanceolatum, Newby			+																+													
marginatum, Lx	+																		+													
multinerve, Heer									+											+												
Nordenskjöldi, Heer			+																+									+				
platanoides, Lx	+																		+													
pubescens, Pursh			B. A.																+												+	
rotundifolium, *Lx*	+																		+													
solitarium, Lx	+																		+													
subrepandum, Hos. & Mck						+														+												
vitifolium, Sap. & Mar																		+			+											
Whymperi, Heer	+																		+									+				
zizyphoides, Heer									+											+												

a (80) Temperate and subtemperate regions of the Northern Hemisphere, Andes; rare in West Indies and Madagascar.

DISCUSSION OF THE TABLE OF DISTRIBUTION.

In attempting to compare and discuss a few of the more salient points which this table brings to light, it will perhaps be most convenient to consider the several groups of the systematic arrangement in their descending order from the primary subdivision into the two great series down to the ultimate subdivision into species. Preliminary to this a few of the leading facts need to be set down.

The whole number of species enumerated in the table is 1,540, of which 286 are Cryptogams and 1,254 are Phanerogams. The Cryptogams consist of 119 cellular and 167 vascular, and the Phanerogams of 115 Gymnosperms and 1,139 Angiosperms. The Angiosperms embrace 160 Monocotyledons and 979 Dicotyledons, and this last subclass is made up of 467 apetalous, 406 polypetalous, and 106 gamopetalous plants. These are the primary groups into which the vegetable kingdom is divided in the natural system, and, with the occasional exception of the last two, vegetable paleontologists almost unanimously adopt the order in which they have just been stated, which is also that of the table. They do this chiefly because it best represents the order in which these groups have appeared in the geological history of the earth, and their relative abundance in the several ascending strata. This, however, is true only as a general proposition, and may not hold in special cases, particularly when adjacent formations are compared. It cannot, therefore, be expected to prove literally true of the three formations we are here considering, nor to have any very great weight in determining the age of the Laramie group. Doubtless if we knew the entire flora of that group, and also the floras of the upper Cretaceous and the Eocene, such a comparison would have considerable weight and serve in large measure to fix the time at which the first of these floras flourished relative to that of the other two. But while we need not anticipate great results in this direction with things as they are, our table enables us to make this comparison, and it will be interesting, to say the least, to do so.

In comparing the leading floral elements of these three formations, however, it is evident that we cannot use the net figures as given above, on account of the occurrence of a considerable number of species in more than one of them, sometimes in all three. The number of such coincidences amounts in our table to twenty-four, making the gross entries in the three columns 1,564 instead of 1,540, and the former of these numbers must be taken as a basis of comparison. These slight additions will be scattered through the different groups, affecting them all more or less. The changes will not, however, at all vitiate the conclusions to be drawn. It is clear that the element to which we must attend is the proportion which the several vegetable groups bear to the total number from each formation, and that a comparison of these percentages in the same group for the three formations will afford us all the basis there is from which to draw conclusions.

The data may be condensed in the following form:

Systematic groups.	Laramie.		Senonian.		Eocene.	
	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.
All plants	323	100.0	362	100.0	879	100.0
Cryptogams	48	14.9	97	26.8	143	16.2
Cellular	13	4.0	18	5.0	89	10.1
Vascular	35	10.9	79	21.8	54	6.1
Phænogams	275	85.1	265	73.2	736	83.8
Gymnosperms	18	5.6	43	12.2	58	6.6
Angiosperms	257	79.5	222	61.0	678	77.2
Monocotyledons	31	9.6	23	6.4	107	12.2
Dicotyledons	226	69.9	199	54.6	571	65.0
Apetalæ	119	36.9	116	31.7	241	27.5
Polypetalæ	84	26.0	66	18.2	263	29.9
Gamopetalæ	23	7.0	17	4.7	67	7.6

An examination of these percentages shows that little light is thrown by them upon the relative age of the Laramie group. While in the Senonian, as theory would require, the Cryptogams have a higher proportion than in the other formations, it will be observed that they have a smaller proportion in the Laramie than in the Eocene, which is contrary to theory. This anomaly, however, is caused by the irregular representation of the cellular Cryptogams, which generally have increased with the later epochs and do not represent the waning types of the ancient floras. The vascular Cryptogams, however, do this, and it is to them that we must look for the confirmation of the theory, if it is to be confirmed. We find that it is here confirmed with sufficient accuracy, the Laramie occupying a position intermediate between the Senonian and the Eocene, though considerably nearer to the latter.

In the Gymnosperms we find the same anomaly as in the total Cryptogams, which in both cases is evidently due to the great predominance in the Laramie group of dicotyledonous forms. That group is, however, exceptionally rich in Monocotyledons, approaching the Eocene in this respect, while this type is meagerly developed in the Senonian. It is the great predominance of palms in the lower Laramie that has led Mr. Lesquereux to insist upon its Eocene facies, and this is certainly evidence not to be ignored. It is known that this type reaches its maximum development in the Eocene, and that to its predominance the special character of the Eocene flora is largely due. If, however, the Laramie group includes the Fort Union beds in one great deposit, with an extensive north and south range, its combined flora will certainly greatly reduce the percentage of these Eocene types, for we must recollect, and I hope soon to demonstrate this fully, that, so far as now published, the flora of the southern districts is given a wholly undue prominence and that of the northern remains as yet for the most part undescribed. Still, this is an anticipation which is out of place here, since the object of our present research is to inquire into the characteristics of the Laramie flora as hitherto published and made known.

The great profusion with which the Dicotyledons are represented in all these floras—amounting to considerably over half the species even in the Senonian, over two-thirds in the Laramie, and nearly two-thirds in the Eocene—makes this group of plants a somewhat more reliable term of comparison than any of the less abundantly represented types thus far considered. Whatever may be thought of the proper place of the Gamopetalæ, so sparingly preserved for us in the fossil state, it is universally admitted that the Apetalæ, or Monochlamydeæ, with their numerous amentaceous genera, furnished the earliest representatives of dicotyledonous vegetation, and that the forms with two floral envelopes (Dichlamydeæ) came later and form a higher type of plants. If we examine the percentages here, we find that the law holds true for the Polypetalæ and Gamopetalæ, which are the rising forms, or at least were so during all three of the epochs under consideration. The percentage is least in the Senonian, intermediate in the Laramie, and highest in the Eocene. In the Apetalæ, however, the maximum development appears in the Laramie instead of in the Eocene, which is not easily explained and probably will not continue to hold true with the more complete elaboration of that flora. These comparisons are with the total floras of the several groups, but perhaps a more interesting result will be obtained if we consider the Dicotyledons by themselves, and then find the relative proportions which the subdivisions bear to the whole in the three formations. Such a comparison will show that in the Laramie group the Apetalæ are 53, the Polypetalæ 37, and the Gamopetalæ 10 per cent. of the Dicotyledons; that in the Senonian the Apetalæ are 58.5, the Polypetalæ 33, and the Gamopetalæ 8.5 per cent. of the Dicotyledons; and that in the Eocene the Apetalæ are 42, the Polypetalæ 46, and the Gamopetalæ 12 per cent. of the Dicotyledons. On the theory that these types progressed in the order named and that the Laramie is intermediate between the other two formations, the relative number of apetalous species should diminish as we pass from the Senonian to the Eocene, which is the case, viz: Senonian, 58.5; Laramie, 53; Eocene, 42. The relative number of Polypetalæ, on the other hand, should rise with the age of the strata, and this we also find to be the case: Senonian, 33; Laramie, 37; Eocene, 46. The Gamopetalæ should also rise with the strata, but more rapidly. The figures are: Senonian, 8.5; Laramie, 10; Eocene, 12. These coincidences of fact with theory are interesting, and in view of the circumstance that they continue to hold from the Cenomanian below to the Miocene above,[1] they can scarcely be regarded as wholly without significance.

The advantage of comparing such large classes consists in the tend-

[1] See Fifth Annual Report of the United States Geological Survey, 1883-'84, pp. 449, 450. For similar data for the comparison of the floras of other formations, see table on pages 440 and 441.

ency of this method to eliminate the disturbing element of geographical distribution, which, as we shall soon see, is the chief obstacle to exact results in the consideration of genera and species. The species may all differ, the genera may be more or less local, even the orders may prevail in certain continents or hemispheres, but the relative predominance of such great types as the vascular Cryptogams, the Gymnosperms, or the Dicotyledons may depend chiefly upon the period in the history of their development, and, therefore, afford a measure of time which is as much more reliable as it is more rude and general than that afforded by the narrower groups of vegetation. Viewed in this light, the data thus far considered, while suggesting nothing more definite, may be fairly claimed to prove that the Laramie age was considerably later than that of the Senonian, and somewhat earlier than that of the Eocene flora.

In the classification of plants according to the natural method the next subdivision after the ones we have just considered is that into natural families or *Orders.* In certain large systematic works, it is true, an intermediate group is often introduced, usually called the *Cohort,* but it will not be necessary or convenient in the present case to treat this subdivision separate from the Order. In the cellular Cryptogams the classification is very unsettled, and the several groups receive different systematic values. The Fungi, Lichens, and Algæ are not always regarded as orders, but they are so rare in a fossil state and of so small importance from the chronological point of view that they may be conveniently so regarded here. Four species of Fungi, consisting chiefly of spots on dicotyledonous leaves (*Sphæria,* Hall) have been described from Laramie strata, while only one such has been reported from the Senonian and only two from the Eocene. The only lichen referred to any of these formations is an Opegrapha from the Laramie. Nearly a hundred species of supposed Algæ have been published from the three horizons, three-fourths of which are Eocene, embracing a large number of doubtful forms described (and often not figured) by Massalongo from Monte Bolca, etc. The Laramie furnishes only eight and the Senonian seventeen. Their diagnostic value may be set down as *nil.* Twelve Characeæ (all belonging to Chara) and four Muscineæ all from the Eocene, complete the cellular Cryptogams, which, for our present purpose, might as well have been omitted from the table.

The Filices, or Fern family, constitute an important order from the point of view of this discussion, furnishing 154 species. As the waning descendants of Carboniferous types that predominated throughout the earlier history of the globe, we naturally expect them to continue to bear in point of abundance some relation to the age in which they are found, the earlier to have precedence over the later. The assumed position of the Laramie group between the other two is borne out by this order, for, although a larger actual number of species occurs in the Eocene than in the Laramie, this number is less in proportion to the total of the two floras. The Laramie flora is 21 per cent. of the three combined floras, the Senonian is 23 per cent., and the Eocene 56 per cent. The quota of each, therefore, were they all of the same age, would be: Laramie, 32; Senonian, 36; Eocene, 87. It will be seen that the Senonian far exceeds its proportion, even assuming for it a considerably lower position. We are thus forced to see in the Senonian flora a much stronger Mesozoic facies than in either of the other groups. No family of plants brings out this fact more clearly than that of the Ferns, but it also speaks with equal authority upon the position of the Laramie below the recognized Eocene plant beds as thus far known.

The Rhizocarpeæ, Equisetaceæ, and Lycopodiaceæ can best be mentioned when we come to consider the genera, and we will now pass to the two gymnospermous orders, the Cycadaceæ and the Coniferæ. The Cycadaceæ, although they have barely survived into modern time, are, as is well known, a characteristic Mesozoic type of vegetation, having attained their maximum development in the Jurassic. They form an insignificant part of the Cretaceous flora and nearly disappear with the Tertiary. The only Laramie species rests upon a single specimen found at Golden, Colorado, and referred by Mr. Lesquereux to the genus Zamiostrobus. Yet seven species belonging to almost as many genera are recorded from the Senonian, again reminding us of the Mesozoic age of this flora.

We are thus brought to the consideration of the Coniferæ, which is one of the most important orders in the vegetable kingdom for the paleontologist. In the three formations under consideration this order has thus far yielded 107 species, of which 17 are found in the Laramie, 36 in the Senonian, and 58 in the Eocene, there being four coincidences. The even quota of each would be: Laramie, 23; Senonian, 26; and Eocene, 62. As the Coniferæ probably attained their maximum development in the middle Cretaceous, that is, earlier than any of the three epochs we are considering, the older of these epochs should show an excess over this quota and the younger a deficit. The Senonian shows such an excess and the Eocene such a deficit, but the Laramie also falls below even farther than the Eocene, which, in so far as the evidence of this order goes, gives it a more modern aspect than the Eocene.

Passing to the monocotyledonous orders, we find them, with the exception of the Palm Family, too small to afford any reliable criterion for the settlement of questions of age. The Naiadaceæ and Gramineæ are the only other orders at all approaching the palms, and both these display decidedly modern characteristics, compared with any of the types hitherto considered. If the palms reached their highest state and greatest abundance in Eocene time, the grasses did not probably attain this position before the close of the Miocene, and it may be doubted whether they have attained it at the present time. The same may be said for the Cyperaceæ and perhaps for the Naiadaceæ. The Liliaceæ and Scitamineæ may have declined somewhat, as have more probably the Aroideæ. It is at least evident that in considering the monocotyledonous orders we are confronted by a set of conditions the reverse of those we met with in the ferns and the Coniferæ, viz: all our formations are now below the period of maximum development of the group under consideration, and the opposite results must be expected. These, in fact, we find. The palms furnish 60 species, which, evenly distributed, would give the Senonian 14, the Laramie 13, and the Eocene 33; but the Senonian gets only 4, while the Laramie gets 17, the Eocene affording the remaining 39. In this important order, therefore, the Laramie is about as fully represented as the Eocene, a fact which has been used to its full extent in arguing for the Eocene age of the Laramie group. If, however, we take the other monocotyledonous orders together, we find that the Laramie (14) falls considerably more below its quota (21) than the Senonian (19) falls below its quota (23), which might equally be taken to argue its Cretaceous age.

In discussing the numerous dicotyledonous orders, we can only select those which are most important, either from their abundance in the fossil state or from certain peculiarities or anomalies which they present. As all trace of the earliest beginnings of this great subclass is still withheld from human observation, it is difficult to describe the rise and decline of its several subdivisions, but it seems probable that the monochlamydeous forms were not only the earliest to appear, but that at the period when we first make their acquaintance (the middle Cretaceous) they had nearly attained their acme of growth and diversity. We then find the large families Salicineæ, Cupuliferæ, Urticaceæ, and Laurineæ in great profusion and highly developed, while many forms which are now dichlamydeous, though they might not then have been so, had already come upon the scene. In examining some of these large orders, the principal question we have to ask is, Does their occurrence in the Laramie group more nearly resemble that in the Eocene or in the Senonian, or rather, assuming that the divergence of the Senonian and Eocene; as known quantities, indicates difference of age, does the divergence of the Laramie from the Eocene indicate for that group an age at all earlier than the latter? The comparison, as in former cases, must be with even quotas and not with the actual figures. The Salicineæ furnish 56 species to the three formations. The quota of the Eocene would be 31, and we find 16; that of the Senonian should be 13, and we find 14. An intermediate position would make the Laramie fall somewhat short of its quota (12). As a matter of fact it more than doubles it (26). So far as this order would indicate, therefore, the Laramie would be decidedly sub-Senonian. This is due to the great predominance of the genus Populus in the Laramie group, of which more will be said hereafter.

The Cupuliferæ furnish 146 species. Of these the Eocene has 58, a number about one-third below its quota (82), while the Senonian has 52, a number as much above. The Laramie occupies a strictly intermediate position, yielding 36 species, or five more than its quota. In the Urticaceæ the Laramie deviates more from the Eocene than does the Senonian and in the same direction as in the Salicineæ, while in the Laurineæ the deviation is again intermediate. In the Juglandeæ we again have the Laramie showing an exaggerated Mesozoic tendency.

We thus see that none of the apetalous orders give the Laramie the same position, from this numerical point of view, as the Eocene, all placing it lower and either intermediate between the Eocene and the Senonian or below the latter.

The principal polypetalous orders are the Araliaceæ, the Myrtaceæ, the Rosaceæ, the Anacardiaceæ, the Sapindaceæ, the Rhamneæ, the Celastrineæ, the Sterculiaceæ, and the Magnoliaceæ. They are much more decidedly Eocene in aspect than the apetalous orders, but less so than they appear with the proportionally large figures in that column. In fact, the Eocene generally only slightly exceeds its quota for the three groups after equalization as explained above, and in the Rhamneæ and Magnoliaceæ it falls below it. A careful inspection of these nine orders shows that in two cases (the Rosaceæ and the Sterculiaceæ) the Laramie holds an intermediate place between the Eocene and the Senonian, that in four cases it holds a place below the Senonian, while in three cases (the Anacardiaceæ, Sapindaceæ, and Magnoliaceæ) its position is indicated as slightly higher than the Eocene.

The gamopetalous orders are small and their indications are readily deduced from a casual inspection of the table. The two largest, the Ebenaceæ and Caprifoliaceæ, consist entirely of the two genera, Diospyros and Viburnum, respectively, and can be treated under the head of *genera*. Taking all the gamopetalous orders together, the Laramie is seen to occupy an intermediate position between the Senonian and the Eocene.

In examining the orders represented in the three formations under consideration, especially the smaller orders, a marked tendency is visible toward the confinement of entire ones to one formation. This is due to geographical peculiarities, a characteristic which, when we come to study the genera, can be no longer ignored.

We are now prepared to consider our subject from the point of view of the *genera*, and before going further it will be necessary to point out some of the difficulties of this method. In vertebrate paleontology the genera are nearly all extinct, and therefore the paleontologist may here legitimately employ his genera as reliable data for the determination of the age of the formations to which they are confined. In vegetable paleontology this is by no means the case. Of the 354 genera represented in the three formations only 165 are extinct, and many of these are so similar to living genera as to be designated by the same names with modified terminations, such as *ites*, *opsis*, *etc.*, and such forms are, with better material and more careful study, being constantly made to take their places as true living genera. The vertebrate paleontologist, therefore, deals with genera as the paleobotanist does with species, and in fact, as is well known, in this department of zoology the term "genus" is given a much more limited meaning than it is in botany, and a rank not far above that of "species" among plants. This is doubtless in great part necessary, and due to nature having drawn classificatory lines, so to speak, at somewhat different points in different scales of being. But it is clear that the paleobotanist cannot compare his genera as the vertebrate paleontologist compares his for the settlement of questions of geologic age. It is, however, true that certain genera which flourish at the present day predominate in certain formations and are rare or absent in others of later age, so as in a true sense to be characteristic of such formations. This does not prove that they subsequently dwindled away and then revived at a still later date, although this might, and probably sometimes does, occur. But the explanation is that several beds of different age are usually in different parts of the world, and the flora of the globe in past time, as at present, has sustained different types of vegetation at different points on its surface. Or, if the beds are nearly over each other, *i. e.*, not far separated geographically, the predominance of certain genera in lower that are rare or absent in higher strata must be explained on the hypothesis of migration or by supposing that the nature of the country at the two points was very different at the time of the respective deposits. It thus comes about that when we speak of the Laramie flora we refer to a definite geographical area at a definite period of time, and when we speak of the Eocene flora we mean the beds occurring at the localities named on our table and a few others grouped together in the last column but one. If the reader will take the trouble to inspect the columns of the table in which the Senonian species are set down he will find that a very marked distinction exists between those of Europe on the one hand and those of America and the Arctic regions on the other, and that the latter resemble much more closely those of the Laramie group. This is entirely because they are in nearer geographical relationship with them.

But it must not be forgotten that genera are capable of great modifications without rendering a change of name necessary, and the practice among paleobotanists has been to crowd everything into living genera that they will contain without doing violence to their accepted attributes. Therefore, an Eocene or a Cretaceous genus, though still living, may embrace forms widely divergent from those now recognized under the same name, so that such genera may really be characteristic of those formations as strictly as though they had become extinct at their close. The principal interest, therefore, centers upon these characteristic genera, by which term we do not here mean either that they are extinct genera, or that they do not occur in higher strata (*e. g.*, Miocene), or in lower (*e. g.*, Cenomanian), or that they are wholly excluded from either of the three formations, but simply that they predominate in some one relatively to the other two.

As already stated, the whole number of genera represented in the three formations is 354. Of these, 32 are confined exclusively (so far as these formations are concerned) to the Laramie group, 62 to the Senonian, and 155 to the Eocene; 49 are common to all three formations, 6 are found in the Laramie and Senonian, but not in the Eocene, 23 are found in the Laramie and Eocene and not in the Senonian, and 27 are absent from the Laramie and found in both the other formations. The number found at only one horizon is therefore 249, the number occurring at two horizons 56, and the number at all three 49. The number ranging from the Senonian to the Eocene, and therefore, regardless of the Laramie, certainly belonging to both Mesozoic and Cenozoic time, is 76.

The discussion of the genera may be conveniently separated into two parts, one of which shall be devoted to the consideration of the evidence in favor of synchronism, and the other to the subject of geographical distribution. The first of these subdivisions will have nothing to do with any of those genera which are, in the sense here employed, characteristic of any one of the three formations, but must be confined to those that are common to two or all three. Such genera, moreover, as are nearly equally represented in each of the three formations can have no weight in establishing the affinity of the Laramie with the one rather than the other, and must also be excluded from our primary comparisons. A further exclusion must be made of those genera which are common to the Senonian and the Eocene but absent from the Laramie, since both these formations are treated as known quantities, and comparison of their common elements could lead to no new results. We are therefore really reduced to such genera as are either confined to the Laramie and Senonian or to the Laramie and Eocene, or are so nearly thus confined as to be fairly characteristic of the two. In deciding such cases we may also properly exclude very small genera, such for instance as are represented by only one or two species in each formation, unless these species be specially diagnostic or very abundant; but we must not at any time lose sight of the fact that it requires about two and a half species in the Eocene to have the same weight as one in either of the other formations.

After carefully scanning the table, I have selected such genera as I think fairly illustrate this point, and they may be set down in their systematic order in two opposing columns, with the number of species belonging to each:

Laramie and Senonian.				Laramie and Eocene.			
Genera.	L.	S.	E.	Genera.	L.	S.	E.
Zamiostrobus	1	1	....	Halymenites	3	....	4
Abietites	2	1	....	Caulinites	2	....	6
Taxites	2	1	....	Sabal	4	1	9
Sequoia	6	9	4	Flabellaria	2	1	4
Taxodium	3	3	1	Alnus	2	1	6
Phragmites	3	1	....	Rhus	5	1	9
Populus	23	9	7	Sapindus	4	1	5
Juglans	8	2	2	Vitis (?)	5	....	3
Platanus	8	2	....	Zizyphus	5	1	8
Cornus	4	2	2	Celastrinites	2	....	4
Acer	3	2	2	Grewiopsis	2	....	6
Rhamnus	12	2	3	Dombeyopsis	4	....	14
Paliurus	2	1	1	Magnolia	6	2	9
Fraxinus	2	1	1				
Viburnum	15	4	2				

We thus have fifteen genera belonging to the first class and thirteen to the second. Both lists would admit of reduction, but some good reason can be urged in each case for retaining it.

We may examine these several characteristic genera somewhat in detail. Beginning with the first list we find a single species of Zamiostrobus in the Laramie and in the Senonian. The latter occurs in the Gosau formation at St. Wolfgang, Austria, the geological position of which is now believed to be definitely settled as upper Cretaceous. The Laramie plant is of a somewhat doubtful character, but is clearly cycadaceous. It was found at Golden, Colorado, lying on the surface in the vicinity of Laramie beds, and is believed to belong to that formation. The genus, like all fossil cycadaceous genera, is strongly Mesozoic, being found as low as the Oolite.

Abietites, two species of which occur in the Laramie, one being found in both the lower and the upper district, is one of the most ancient of the typical coniferous forms, being found all the way from the Wealden to the Miocene, except in the Eocene, where it is thus far absent. The only Senonian species comes from the Harz district.

The form distinguished as Taxites seems to belong to the northern portion of the western hemisphere, the two Laramie species being reported from British America, and the Senonian species from the beds of Patoot, Greenland. A true Taxus occurs in the London clay, and this seems to be a geographical variety.

No coniferous form is more abundant in the Laramie than Sequoia, six species of which are distinguished. Of the nine species from upper Cretaceous strata all but one are found in the western hemisphere. This furnishes an excellent illustration of the extent to which certain types persist with modification in the same or adjacent territorial areas. There is no doubt that should upper Cretaceous beds be found within the United States these forms will occur as the direct ancestors of the Laramie species. Their rarity in the Old World is seen also to be a fact of geographical and not of geological significance, for it is true of both the Cretaceous and the Eocene.

The genus Taxodium, two of the species of which are so abundant in the Laramie, Senonian, and Miocene, is curiously scarce in the Eocene, and therefore claims a place in our first column.

It is in the Gymnosperms, therefore, that those characters appear which give to the Laramie flora such a strong Cretaceous facies. We find this quite otherwise in the next group, the Monocotyledons. Only in one genus (Phragmites) of this subclass do we find the Eocene wanting. This genus occurs abundantly in the Laramie, and the only Senonian species reported is from the Pacific coast of America, so that it seems that in pre-Miocene time the type was confined to the western hemisphere.

It is, however, among the Dicotyledons, and chiefly in the Amentaceæ, that the most notable examples occur to show the similarity of the Laramie to the Senonian flora, and also its unique character as compared with any other formation. Its 23 species of Populus form one of the greatest of its anomalies, and stamp it with a special character. The nine species of the Senonian cause that formation to partake somewhat of this character, but when we see that all but two of these come from the Vancouver beds or from Greenland we see that this is a distinctly American type.

The genus Juglans, with its eight Laramie, one Vancouver, and one Patoot species, is of special interest in the light of the numerous forms of Carya and Juglans which persist in the American flora. The fossil forms of Juglans may well have been the ancestors of our hickories as well as of our walnuts.

Neither of the two last-named genera, however, can claim as great a share of our interest as does the genus Platanus. With its eight Laramie and two Greenland species, and its entire absence from the Eocene, it seemed to constitute in pre-Miocene time one of the characteristic vegetable types of America.

Passing over the two polypetalous genera, Cornus and Acer, which in like manner belonged during this epoch almost entirely to the west, we come to Rhamnus, with twelve Laramie species; one of the Senonian species is also western (Patoot). Paliurus is an allied genus and is similar in its range to Rhamnus.

Of gamopetalous genera, Fraxinus, though small, belongs to the class we are considering, while Viburnum is, next to Populus and Platanus, the largest and most characteristic of that class. With fifteen species in the Laramie, four in the Senonian, and the two Eocene species from the lowest beds of that age, it seems to be a very ancient type, and one which goes far to separate the Laramie flora from that of the Eocene.

If there were no cases which could be cited to offset this array of evidence, it might seem that no two floras could be more distinct than those of the Eocene and the Laramie, but as we pass rapidly down the opposite column we shall see that there certainly are some bonds of union.

It was long maintained that the peculiar fucoids called Halymenites were characteristic of the Eocene, being so abundant in the Flysch of Switzerland, and their presence in the Laramie strata was put forward as a proof of the Eocene age of that group, but they are now known to occur in the Cretaceous, though absent from the Senonian beds, and as low as the Jurassic. They also extend upward to the Miocene.

The two species of Caulinites from the Laramie differ widely from those of the Paris Basin, but probably belong to that type of plant and in so far assimilate the Laramie to the Eocene flora. It is, however, the palms that have been chiefly relied upon to establish the Eocene character of the Laramie. The evidence here must be admitted to be strong, and their absence from the Senonian beds serves to add to its force. The Eocene was the age of palms. The numerous fruits referable to that family found in the London clay and also at Monte Bolca, constitute one of the leading features of the flora of that epoch, and these are in a manner paralleled in some parts of the Laramie, notably in the tufa beds at Golden, by the many nut-like bodies which Mr. Lesquereux has designated by the term *Palmocarpon.* But aside from these, and probably from the same trees that bore them, we have four species of Sabal and two of Flabellaria represented by leaves in the Laramie flora, though nearly all these palms are found in the lower districts. It is only this lower Laramie that has been claimed as Eocene, and if we restrict the term to this flora its affinity to that of the European Eocene is greatly strengthened.

The genus Alnus is well represented in the Eocene, especially in the Paleocene, and one abundant species is found in the Laramie group. The Senonian species is from Greenland and may have been the progenitor of the wide-spread arctic form *A. Kefersteinii,* Göpp., so celebrated in the Miocene beds of the North.

The Marquis Saporta finds eight species of Rhus in the gypsum beds of Aix in Provence, and the genus also occurs in all the Laramie horizons. The type therefore is common to the two formations and serves to assimilate the two floras. The one Senonian species is from the Quedlinburg beds.

Sapindus predominates in the Fort Union group and in various Eocene localities, and in so far tends to identify the upper Laramie with the Eocene; but such evidence is very feeble. Vitis is a strong Laramie genus, but it occurs sparingly in the Eocene. It therefore scarcely belongs in this list. Zizyphus differs from the other two prominent rhamnaceous genera, Rhamnus and Paliurus, in extending into the Eocene. It is a fair representative of the class we are now considering that indicate a resemblance between the Laramie and the Eocene floras.

The Celastraceæ are highly characteristic of the Eocene, and one form which has been distinguished as Celastrinites is found in the Laramie. The Eocene species of this genus are all from Sézanne, and furnish another evidence of the truth of Mr. Lesquereux's statement in his "Cretaceous and Tertiary Flora" that the flora of the Laramie resembles that of Sézanne more closely than it does that of the Eocene proper. A still more striking illustration of the same fact is found in Grewiopsis, which is the Paleocene form of the Miocene genus Grewia, also occurring in the Laramie.

Dombeyopsis is one of the best marked Eocene genera, but it is almost exclusively confined to Monte Bolca. Its occurrence in the Laramie group is a singular fact and one that has often been brought forward in support of the Eocene age of that group.

The Magnoliaceæ are a very ancient type of plants, species of Liriodendron being abundant in the Cenomanian. The genus Magnolia, which occurs in the upper Cretaceous beds of the Peace and Pine Rivers in British America, is abundant in both the Laramie and the Eocene. It is simply a persistent type.

We have thus rapidly run over the evidence furnished by these two classes of genera for and against the view that the Laramie flora bears such a resemblance to the Eocene flora as to suggest the substantial synchronism of the two series of deposits. It is perhaps best to leave the reader to form his own judgment as to the result, but in the light of former discussion of this question the caution against mistaking horizontal for vertical distribution, may not be out of place. In the great majority of cases, as has been pointed out under each genus, the types persist through different ages in the same or adjacent parts of the the world, and the absence of Laramie types in the Eocene, and *vice versa*, is due to the wide geographical separation of the beds of the two formations. Closer study of the table will show that most of the European genera can be traced from the Cenomanian up to the Miocene of that continent, while most of the American genera can be traced from the Dakota group up to the Miocene of Alaska and Greenland. That some genera should be common to both hemispheres was to be expected, but that these distinctly argue either the Eocene or the Cretaceous age of the Laramie beds cannot be reasonably maintained.

This is the proper place, before descending to specific details, to consider this interesting subject of geographical distribution in its relation to the present plant life of the globe. The present distribution of vegetable forms upon the earth's surface, as all know, is very varied, and several learned and largely successful attempts have been made to trace the lines of migration of plants during their long and often tortuous pilgrimages since Miocene times, driven as they have been by successive alterations of climate, of sea and land surface, and of mountain and plain. But we have seen that the flora of the globe, even as early as the Cretaceous, was far from uniform at all points, and that that of the eastern and western hemispheres in late Cretaceous and early Tertiary time was widely different. We now find that the degree of change since those epochs has been different at different points and far greater in Europe than in America. The data contained in the foot-notes to our table enable us to demonstrate this, and also to show what parts of the globe contain at the present time the leading elements of each of the fossil floras under consideration. If we exclude those genera which are abundant in all three formations, and take only those that are either wholly or principally confined to one of them, we shall perceive that the greater part of the properly Laramie genera are represented to their fullest extent in the present flora of North America or eastern Asia, though many belong to the warmer parts of America, and to India. On the other hand we are struck by the very large number of Australian and African forms in the Eocene flora. The Proteaceæ and Myrtaceæ abound in the Eocene as do the Leguminosæ, the latter chiefly of South African types. We also find that the Senonian flora must be separated into two classes, those from British America and Greenland falling into the same general geographical group as those of the Laramie, while those of the European beds resemble the Eocene flora in this respect. I had intended to elaborate these chorological features more at length and to give a detailed analysis of the three floras from this point of view, but space will not admit of this in the present paper, and as all the data for such an analysis exist in the preceding table of distribution the work of compilation may be left to such as are particularly interested in this feature of the discussion. The results upon their face fully bear out the statement already made that the flora of the Laramie group furnishes evidence of having descended more or less directly from that of the Cretaceous of this continent, and in many cases the lines of descent can be traced through the upper, or Senonian beds to those of the Dakota group, or American Cenomanian.

We are now prepared to compare the three floras under consideration from the usual point of view of their specific relationships, and if the treatment of this part of the subject is brief it is for the very reason that it has already been largely accomplished by others. Still, as already remarked, Mr. Lesquereux only embraces the flora of the lower districts, exclusive of Carbon and Evanston and a few Upper Yellowstone localities, in his Laramie group, while our table combines all these beds with the entire Fort Union deposit of the Upper Missouri and Lower Yellowstone. As these latter were, and by many are still, regarded as Miocene, and certainly contain a flora differing in many respects from the rest, the general complexion of the whole will be considerably modified by including them.

By inspecting the table we observe that only a single species, *Sequoia Langsdorfii*, is common to all three of the formations. This species is generally northern in the western hemisphere, but it is found in the Laramie at Black Buttes, in the Fort Union group, and in the northern extension of this latter in British America. It also occurs in the Cretaceous deposits of Nanaimo, Vancouver Island, and in the Senonian beds of Patoot, Greenland. Professor Gardner finds it in the Eocene deposits of the Isle of Mull, and Massalongo enumerates it in his Miocene flora of Senegal.

Only one other Laramie species, *Ginkgo polymorpha*, is found in any of the Senonian beds, and this occurs also at Nanaimo. Its Laramie locality is the place near Fort Ellis in Montana designated as "six miles above Spring Cañon," which we have seen reason to regard as a western member of the great Fort Union deposit.

The number of Laramie species that also occur in the Eocene as defined in the table is quite large, amounting in all to thirteen or fourteen. Seven of these are confined to these two formations, which might afford strong prima facie evidence of the close affinities of the Laramie and Eocene floras. This evidence, however, is greatly weakened when we perceive that of these seven four occur in the supposed Eocene beds of Mississippi and not in any of the Old World deposits. This is certainly strong proof of the close relationship of these Mississippi beds to those of the Laramie, as well as of their similarity of age, but it is more interesting as showing that in those early times one great homogeneous flora stretched all the way across the North American continent, and that similar forests fringed the waters of the Gulf of Mexico during their southward retreat, and those of the Laramie Sea as it shrunk to the proportions of inland lakes. The difference of time between the two deposits, though it might have been great, was not sufficient to alter the specific identity of these four forms and doubtless of very many others, while in other cases the Laramie species may represent the ancestors of the Eocene species found or to be found in the more eastern deposits. These species are, *Sabal Grayanus*, *Populus monodon*, *Magnolia Hilgardiana*, and *M. Lesleyana*, all of Lesquereux. All except *Magnolia Hilgardiana* occur only in the typical Laramie deposits of the more southern districts, but this species has now been reported also from the Yellowstone Valley, which, of course, relegates it to the Fort Union group.

The other three Laramie species which are otherwise confined to the Eocene are *Halymenites minor*, found in the Flysch of Switzerland, *Ficus Dalmatica*, found in the supposed upper Eocene beds of Monte Promina in Dalmatia, which some authors place higher, and *Sterculia modesta* of

Saporta (not of Heer) found at Sézanne. These three Eocene localities represent the highest and lowest Eocene, and fairly exhibit the degree of homotaxy subsisting between these formations.

The remaining six species that occur in the Laramie and the Eocene, possess less force in this direction from the fact that they are all found in other and higher formations also. Most of them are plants that are abundantly represented in nearly all the more recent deposits, such as *Taxodium Europæum*, found all the way from the Middle Bagshot of Bournemouth to the Pliocene of Meximieux, *Ficus tiliæfolia*, *Laurus primigenia*, and *Cinnamomum lanceolatum*, abundant in nearly all the Oligocene and Miocene beds of Europe. *Quercus chlorophylla* occurs in the Mississippi Tertiary as well as at Skopau in Sachs-Thüringen, and is also abundant in the Miocene, and *Ficus tiliæfolia* is found in the Green River formation at Florissant, Colorado. The only other species belonging to this class is *Goniopteris polypodioides*, which occurs at Monte Promina and in the Miocene of Rivaz. *Alnus Kefersteinii*, once reported from Aix in Provence, is considered doubtful, and should probably be excluded from the list of Eocene plants, but it is found in the American Eocene of both Florissant and Green River. In the Laramie it is only known from the Evanston coal beds, and is most abundant in the arctic Miocene of Alaska, Spitzbergen, etc., but it is also common in the Miocenes of Northern and Central Europe.

This is all that can be said in favor of the Eocene character of the Laramie flora, and were it not capable of being further weakened, the case might be regarded as somewhat stronger than that of the genera; but there still remain many important considerations which affect the legitimacy of some of these facts. For example, we have seen that fourteen species altogether occur in the Laramie and the Eocene; but the number occurring in the Laramie and formations higher than Eocene is sixty-two. Thirty-five of these are confined to the Laramie and Miocene. Two (*Diplazium Mülleri* and *Flabellaria Zinkeni*) are confined to the Laramie and Oligocene, while twelve occur in Laramie, Oligocene, and Miocene strata. These species are by no means confined to those that have only been found in the northern districts, but, as any one can see by examining the table, they come largely from the typical beds, and include such species as *Sabal Campbellii*, *Salix integra*, *Betula gracilis*, *Ficus asarifolia*, *Rhamnus alaternoides*, etc.

It would certainly be very unsafe from this to argue that the lower Laramie is Miocene. With such a vast flora as the Miocene, numbering as it does (including the Oligocene beds) nearly 4,000 species, it is reasonable to expect that as many Laramie forms as are found common to the two formations (about 1½ per cent.) should persist nearly unchanged from one epoch to the other. As a matter of fact, a much larger percentage of forms thus persists where the two deposits occupy nearly the same geographic area. Some four or five of the Laramie species are still found in the living flora, most of them in North America, unchanged, so far as can be judged by the organs (chiefly appendicular) that have been found in the fossil state. The two species of hazel, and also the sensitive fern from the Fort Union deposits regarded by Dr. Newberry as identical with the living forms, must be specifically so referred until fruits or other parts are found to show the contrary. The bald-cypress of the Laramie swamps seems not to have been specifically distinct from that of the swamps of the Southern States, and, as I shall soon show, forms of the Ginkgo tree occur not only in the Fort Union beds, but in the lower Laramie beds at Point of Rocks, Wyoming Territory, which differ inappreciably except in size of leaf from the living species.

To the strong evidence against the Eocene age of the Laramie group afforded by the persistence of so many of its types into periods much more recent than Eocene may perhaps be added evidence equally adverse but of the opposite nature. A few Laramie forms occur in Cretaceous strata. *Sequoia Langsdorfii* is found, as we have already seen, in the Cretaceous of both British Columbia and Greenland, and *Ginkgo polymorpha* in the former of these localities. *Cinnamomum Scheuchzeri* occurs in the Dakota group of Western Kansas as well as at Fort Ellis. Sir William Dawson detects in strata regarded as Laramie by Prof. G. M. Dawson, of the Geological Survey of Canada, a form which he considers to be allied to *Quercus antiqua*, Newby., from Rio Dolores, Utah, in strata positively declared to be the equivalent of the Dakota group.

Besides these cases there are several in which the same species occurs in the Eocene and the Cretaceous, though wanting in the Laramie. *Cinnamomum Sezannense*, of the Paleocene of Sézanne and Gelinden, was found by Heer, not only in the upper Cretaceous of Patoot, but in the Cenomanian of Atane, in Greenland. *Myrtophyllum cryptoneuron* is common to the Paleocene of Gelinden and the Senonian of Westphalia, and the same is true of *Dewalquea Gelindensis*. *Sterculia variabilis* is another case of a Sézanne species occurring in the upper Cretaceous of Greenland, and Heer rediscovers in this same Senonian bed the Eocene plant, *Sapotacites reticulatus*, which he originally described from Skopau in the Sachs-Thüringen lignite beds.

Before commencing this discussion from the point of view of specific relationship it was remarked that it would differ from that just closed, where the subject was treated from the point of view of generic relationship, in dealing with geological, or time relations, rather than with geographical, or space relations. But we have already seen that the latter considerations could not be kept wholly out of view, and we shall now see that they really form a very important part of this mode of treatment, if it is to be made at all complete. Of the seven species confined to the Laramie and Eocene it was seen that four were also confined to this continent. This anomaly arose from having placed the Mississippi Tertiary in the last column of Eocene localities. But the Green River group, which is by most geologists regarded as the Eocene of Western

America, was purposely left out of the body of the table, for reasons which have been stated. A column, however, was employed to record the occurrence in that group of species belonging to any of the three formations. An inspection of this column shows that 21 species are common to the Laramie and the Green River groups. Admitting this to be Eocene, as well as the Mississippi Tertiaries, we have 26 species common to the Laramie and American Eocene against 10 that are common to the Laramie and European Eocene; this notwithstanding that the American Eocene embraces less than a third as many species as the European.

We may carry this analysis further. There are 39 species common and confined to the Laramie and the Miocene (inclusive of the Oligocene). Of this number 21 are found in the American Miocene. Three others occur in the arctic flora of Spitzbergen, Siberia, and other localities not in the western hemisphere, but the complete unity of the arctic Miocene, and its almost total dissimilarity from the Miocene of Europe, fairly warrant their addition to the American flora. Fifteen of these are not found at all in the Miocene flora of Europe. This is surprising when we consider how very small this combined North American and arctic Miocene flora is compared with that of Europe.

If we now divide the Laramie species that are also found in other formations and localities into two classes, one of which shall embrace all those occurring in American beds other than Laramie and the other those occurring in no other American strata than those of the Laramie, we shall have 55 such species out of a total of 80, 30 of which are confined exclusively to the western hemisphere. The significance of these figures, let me repeat, is greatly increased when we consider in the same connection the magnitude of the European Tertiary flora, as compared with that of America.

We are thus brought once more face to face with the fact that while the floras of Europe and America differed widely in character during late Cretaceous and Tertiary time, the beds of different age in each, respectively, contained floras resembling each other to such an extent as to warrant the conclusion that the later ones had descended from the earlier without more than the natural amount of modification. When, therefore, we couple these facts with those presented above as to the relationships of the fossil to the living flora of the globe (where it appeared that the American fossil flora resembles that of eastern North America and southeastern Asia, while the European fossil flora resembles that now found in Australia and the eastern half of the southern hemisphere generally), we must conclude that some great disturbing agencies have been at work since Miocene times which have caused extensive migrations and profound alterations in the plant life of the globe. It is no part of my purpose at present to discuss this problem, and I need scarcely say that it is to the influence of a series of great fluctuations of temperature, causing glacial epochs, that these changes are principally attributed, and that a thorough study of the living flora in comparison with the Tertiary flora not only bears out this conclusion to a remarkable degree, but renders it possible to trace many of the lines of migration and to fix with some precision both the space and the time relations of glacial phenomena.

We may now briefly revert once more, and for the last time, to the question of the age of the Laramie group, in so far as this is indicated by the similarity of its flora to that of other formations. Thus far I have confined myself to the published flora of that group in order to ascertain how the case stood at the close of the prolonged discussion which has been outlined relative to its age, in which discussion Mr. Lesquereux has had the last word in his recent great work on the Cretaceous and Tertiary Floras of the West. But I should admit that I was led to consider this side of the subject by the occurrence in my own collections from both the northern and the southern districts—in the Lower Yellowstone Valley and along the Upper Missouri, at Golden and other points in Colorado, at Carbon, Black Buttes, and Point of Rocks, Wyoming, and at other localities—of new forms, some of them unique and remarkable, but some bearing a striking resemblance to, or identical with, forms already figured from other localities whose stratigraphical position is definitively settled. While some of this latter class have a Miocene aspect, as does the Fort Union flora in general, there are others embodying the characters that are usually associated with the Cretaceous flora. As already remarked, it is too early for me to discuss these forms fully or in detail, although some of the more remarkable or representative ones are figured in the illustrations at the close of the paper. At present I can merely call attention to some of these forms of Cretaceous aspect, as showing that the more familiar we become with this flora the more closely we find it linked with the Cretaceous floras below it, and particularly with those of America.

There seems some reason to believe that we now have in Fort Union strata a somewhat modified representative of the hitherto exclusively Cretaceous genus *Credneria*, so long known from the upper Cretaceous beds of Blankenburg, in the Harz Mountains, since found in other European strata of the same or earlier age, and now added by Heer to the middle Cretaceous flora of Greenland. *Credneria* is the original form upon which have since been erected the additional genera of the group *Ettingshausenia*, *Protophyllum*, and *Aspidiophyllum*. These are all characteristic Cretaceous genera, Credneria and Protophyllum being found both in the Senonian and the Cenomanian, and Aspidiophyllum being confined to the Dakota group. Our form (Plates LVII and LVIII) differs somewhat from all that have thus far been described, and may be sufficiently divergent to warrant the establishment of a new genus, or it may be necessary to refer it to some other genus, but its resemblance to *Credneria* is sufficient at least to make it a strongly Cretaceous type, and should its relationship to that genus be finally settled it must certainly possess weight in the general problem of geologic age. It is also noteworthy that this form comes from the Fort Union beds on the Lower Yellowstone, and from one of the highest strata of this formation that are represented in that section.

There occur in the collections a large number of querciform leaves, probably for the most part referable to the Cretaceous genus *Dryophyllum*, established by Debey as the receptacle for the numerous archaic oaks which he found in the iron sands of Aix-la-Chapelle. Until quite lately this genus was very little known, and chiefly from specimens furnished by him to different museums in Europe, but within the past two years he has published a small pamphlet with one plate, illustrating several of the forms.[1] The material seemed rather obscure and fragmentary, and the figures are very rude, but they enable us to gain a better idea of the limits of the genus than was otherwise possible. We have from the Laramie group forms closely allied to several of Debey's species of Dryophyllum, such as *D. Eodrys*, *D. gracile*, *D. cretaceum*, *D. Aquisgranense*, etc., although it is hardly probable that any of these species actually flourished in America.

There can scarcely be a doubt that we have in Figs. 8 and 9, Plate XL, the Cretaceous species *Platanus Heerii* of the Dakota group and arctic Cenomanian strata. Compare, for example, fig. 1 of plate vii, in the sixth volume of Heer's "Flora fossilis arctica," Part II, Cretaceous flora of Greenland.

Several forms of Hedera have a Cretaceous aspect, and it is quite probable that *H. primordialis*, Heer, from the Greenland beds at Atane, may be represented by our Fig. 4, Plate XLVIII.

In Fig. 1, Plate LX, we have a form which, for so much of the leaf as is present, resembles the figures of similar portions of Heer's *Populus Stygia* (Fl. foss. arct., Vol. III, Kreidefl. v. Grönland, plate xxix, fig. 10; Vol. VI, Abth. II, Kreidefl. v. Grönland, plate xvii, figs. 5, 7; plate xxxix, fig. 5). But for the great resemblance to these figures, I should have certainly regarded it as a Liriodendron, and notwithstanding this resemblance I am inclined to refer it to that genus. But Liriodendron is rather a Cretaceous genus, although the broad-leaved forms like this occur also in later strata and form the type to which the living species belongs.

I have not mentioned the singular cryptogamous form that was collected both at Iron Bluff and at Burns's Ranch, although I am now convinced that it is a Cretaceous form, because up to the time when it was necessary to submit this paper it had not been sufficiently studied and the drawings were incomplete; but upon careful comparison I am satisfied that it is the same plant that is figured by Dawson in his paper in the Transactions of the Royal Society of Canada (plate i, fig. 3) as

[1] Sur les feuilles querciformes des sables d'Aix-la-Chapelle, par le Dr. M. Debey, d'Aix-la-Chapelle. Extrait du Compte rendu du Congrès de botanique et d'horticulture de 1880. Deuxième partie. Bruxelles, 1881.

Carpolithes horridus. To the parts represented there our specimens add the complete rays showing what is probably the spore-bearing portion at their extremities.

Other Cretaceous forms might be mentioned, but the above-named types are sufficient to show that the flora of the Laramie group certainly possesses a strong Cretaceous facies, and in very many respects agrees with that of the Senonian or highest member of that formation wherever this is known to contain vegetable remains. I do not wish to be understood as arguing that the Laramie is a Cretaceous deposit, but rather against the view maintained by Mr. Lesquereux that it is necessarily Eocene. I am still free to admit that, so far at least as the Fort Union group is concerned, the flora is closely in accord with that of the European Miocene, in which nearly all its genera and many of its species are represented; and but for the occurrence of these anomalous, archaic forms, which become more and more frequent as the material for study increases, it would be impossible to deny that the flora at least was Miocene. In this, however, one fallacy should be avoided, which is, I think, the one that so strongly biased Professor Heer in favor of referring new and imperfectly known floras to the Miocene. The immense number of fossil plants that are known from that formation—over 3,000 species—greatly increases the chances of finding the analogue of any new form among its representatives. While, for example, there are probably many more Laramie forms that have nearer allies in the Miocene flora than in that of any other age, still, relatively to the number of Miocene species, the Eocene or Senonian types would outweigh them. But the same canon must be applied in comparing the Laramie with these latter. If the relationships were about equal we should require a larger absolute number of Eocene forms, because the Eocene flora is larger

Taking all these facts into consideration, therefore, I do not hesitate to say that the Laramie flora as closely resembles the Senonian flora as it does either the Eocene or the Miocene flora. But again, I would insist that this does not necessarily prove either the Cretaceous age of the Laramie group or its simultaneous deposit with any of the upper Cretaceous beds. The laws of variation and geographical distribution forbid us to make any such sweeping deductions. With regard to the first point it is wholly immaterial whether we call the Laramie Cretaceous or Tertiary, so long as we correctly understand its relations to the beds below and above it. We know that the strata immediately beneath are recognized upper Cretaceous and we equally know that the strata above are recognized lower Tertiary. Whether this great intermediate deposit be known as Cretaceous or Tertiary is therefore merely a question of a name, and its decision one way or another cannot advance our knowledge in the least.

With regard to the synchronism, as already remarked, it would certainly be interesting and important if we could know with certainty what other deposits on the earth's surface were being made at the same time with those of the Laramie. But we have seen that this cannot be known for any very widely separated areas. Within the Laramie group, however, conclusions of this nature are comparatively reliable, and when more is known of this flora and of the characteristic types of different horizons within it, and different areas occupied by it, there can be no doubt that its value in the determination of the precise horizon of new beds both within and without that group must be very great. The following words of Mr. Meek, after a careful survey of the question from the point of view of the invertebrate paleontologist, are equally true for fossil plants: "But it may be asked," he says, "are we to regard all such fossils as of no use whatever in the determination of the ages of strata? Certainly not, because, even in case future discoveries in this country and the Old World should never modify the present conclusions in regard to the geological range of * * * these types * * * so as to enable us to use them with more certainty as a means of drawing parallels on opposite sides of the Atlantic, they will undoubtedly be useful, when viewed in their specific relations, for the identification of strata within more limited areas. That is, when all or most of the details of the stratigraphy of the whole Rocky Mountain region and the vertical range of species have become well known, these fossils will perhaps be found nearly as safe guides in identifying strata at one locality with those of others there, as many other kinds."[1]

But there is a higher ground on which investigations of this nature may be justified. However negative the results may prove, in seeking to make wide generalizations, either for geology or for biology, every new form discovered widens our knowledge of what has been taking place on the surface of the earth since its crust was formed, and the additional knowledge we thus gain of the history of the globe is worth for its own sake all that its laborious pursuit costs, and this quite aside from the added value it possesses in furnishing an ever widening basis for the true laws of both geologic and biologic development.

RECENT COLLECTIONS OF FOSSIL PLANTS FROM THE LARAMIE GROUP.

I have now completed the review of the flora of the Laramie group which, as stated at the outset, would constitute the first part of this memoir, and will now present the concluding portion, also outlined at the beginning, which will be of a somewhat personal character, and will consist of an attempt to record so much of the little that I have been able to contribute to the stock of knowledge relative to the Laramie flora as has thus far assumed a sufficiently definite form. It is, however,

[1] Report of the United States Geological Survey of the Territories. F. V. Hayden, Geologist-in-charge. Vol. IX. A Report on the Invertebrate Cretaceous and Tertiary Fossils of the Upper Missouri country. By F. B. Meek, p. lxi.

proper to state that the record I have made will not be complete until I shall have bestowed a large amount of attention and study upon the material in hand. The specimens figured can scarcely be said to have been selected as representative of my collections, although they are so to some extent, but they rather indicate what forms had been sufficiently studied at the time I began to prepare this paper to warrant publishing the figures. The names which I have affixed to them are therefore provisional only, and subject to alteration in the course of the preparation of my final report, which has been merely arrested long enough to enable me to prepare and present in the present synopsis some general considerations which would necessarily be crowded out of the detailed work.

My collections were all made in two seasons, that of 1881 and that of 1883. On the first of these occasions I visited a number of the localities belonging to the lower series situated in Colorado and Wyoming. On the second occasion I visited the valleys of the Lower Yellowstone and Upper Missouri Rivers, and found fossil plants in what are undoubtedly typical Fort Union strata. The itinerary and a general description of the field work of these two seasons have been given in my administrative reports for those years.[1]

COLLECTIONS FROM LOWER LARAMIE STRATA.

The collections made at Golden, Colorado, have not proved particularly rich, and probably very little will be found in them that has not already been reported from that locality. Large palm leaves (*Sabal Campbellii*) and numerous fragments of leaves of Platanus, Ficus, etc., were found in a coarse friable sandstone, either ferruginous and light red, or siliceous and gray or white, in the valley between the Front Range and the basaltic Table Mountain on the east. These strata stand nearly vertical and are in immediate juxtaposition to the productive coal beds on the west. The coal mines themselves are worked in vertical beds which have Cretaceous strata on the west and these coarse sandstones on the east, showing that the direction from east to west represents the descent through the several layers and that the coal veins are at the very base of the Laramie at this place. The strata are conformable, and both the Cretaceous and the Laramie are tilted so as to be approximately vertical. At the base of South Table Mountain the strata are horizontal, and the line dividing the vertical from the horizontal strata could be detected at certain points. A measurement from this line to the base of the coal seam was made at one place and showed 1,700 feet of the upturned edges of Laramie strata. It is probable that we here have the very base of the formation.

The geology of Golden is very complicated, but my observations led

[1] Third Annual Report of the United States Geological Survey, 1881–'82; pp. 26–29. Fifth do., 1883–'84, pp. 55–59.

me to conclude that during the upheaval of the Front Range a break must have occurred along a line near the western base of Table Mountain, forming a crevice through which issued the matter that forms the basaltic cap of these hills. The eastern edge of a broad strip of land lying to the west of this break dropped down until the entire strip of land assumed a vertical position or was tilted somewhat beyond the perpendicular. This brought the Laramie on the east side of the Cretaceous with its upper strata at the extreme eastern, while the coal seam at its base occupied the extreme western side of the displaced rock. The degree of inversion varies slightly at different points and may have been much greater in some places. This will probably account for the discovery at one time of a certain Cretaceous shell (Mactra) *above* a vein of coal in a shaft about 4 miles north of Golden, and about which considerable has been said in discussing the age of the Laramie group. I visited the spot, but found the strata so covered by wash that I was unable to determine their nature.

The collections made at the base of South Table Mountain in a dark and very soft, fine-grained, siliceous-ferruginous sandstone, commonly called tufa, were both more abundant and better preserved than those from the valley, and in them have been found several rare and interesting forms. *Ficus irregularis* was one of the most common, and *Berchemia multinervis* was found. Palms abounded, but only as fragments of narrow portions of leaves. On the surface of the ground, quite well down toward the bottom of the valley, were found numerous fragments of palm wood in the silicified state, as chert, very hard and admitting a high polish. The leaf scars are clearly exhibited, and the vascular bundles and ducts are beautifully shown in cross and longitudinal sections.

At the locality known as Girardot's coal mine, some 5 miles east of Greeley, Colorado, on the open plains, Laramie strata were found containing characteristic mollusks in great abundance, but no plants except the wide-spread *Halymenites major*, which occurred in profusion immediately over the shell beds. Large branching forms were found, as well as forms variously curved and crooked. They seem to be to some extent concretionary, and are composed of iron oxide and sand with a little calcite.

At the mouth of the Saint Vrain, near Platteville, where a day was spent, these forms occurred again in equal abundance and variety. Two species were found here, and perhaps three. Specimens of petrified wood from a large stump, probably coniferous, were collected, but no traces of any other form of plant life were detected. At this point we seem again to have the very base of the Laramie overlying a bluish Cretaceous clay.

The collections from Carbon Station, Wyo., are much more satisfactory than those from the Colorado beds. The station and adjacent track of the Union Pacific Railroad at this point are located in a monoclinal valley running north and south, or at right angles to the railroad. A fault occurs near the station by which the strata on the southwest are lower than those on the northeast. The coal seams on the east and north are close to the surface and sometimes crop out. They pass downward from south to north with a dip of about 15 degrees, reaching across the monoclinal valley through which the railroad runs. On the west and south they grow deeper and have mostly ceased to be worked. The fossil plants, which are very abundant, are always above the coal, and the strata in which they are richest lie five to ten feet from the highest coal seams. Immediately above the coal is a layer of arenaceous limestone, which is generally shaly, but sometimes solid and very hard ("fire clay"). Even in this a few plants occur, but it was nearly impossible to obtain them. The plant beds proper are fine-grained more or less ferruginous and calcareous sandstone shales, quite easily worked, and from them some beautiful specimens of Cissus, Paliurus, and other genera were obtained. These beds are doubtless somewhat higher than those of Black Buttes and Point of Rocks, but they are probably within the limits of the Laramie formation and seem to be the equivalent of the Evanston coal.

The locality denominated Black Buttes always refers to the station of this name on the Union Pacific Railroad, 140 miles west of Carbon Station and in full view of the black rock from which it takes its name. This had been reduced to a mere section house at the time of my visit, and all traffic was by freight trains. It is in the valley of the Bitter Creek, and typical Bitter Creek strata are alone seen. The railroad here runs nearly north and south. The strata dip to the southeast. Opposite the station on the east there are about 100 feet of fucoidal sandstone at the base, above which are two prominent coal seams separated by shales. The coal varies in thickness in both seams and is from three to eight feet thick, the lower seam being perhaps the better in quality. Not more than two feet above the lower coal seam the rocks commence to be plant-bearing. They are reddish on the exposed outer surface, but bluish-gray within, somewhat laminated, and consist of a hard, compact, and very arenaceous limestone. They yield beautifully preserved specimens of leaves, which form the only planes of cleavage.

Above the upper coal the shales are very thin, and their surfaces, where not exposed to the weather, are generally covered with a profusion of very small prints of leaves, stems, culms, fronds, etc., but so fragmentary that little can be done with them. Half a mile north of the station the lower coal seam descends to near the level of the railroad, but the succession of the strata can still be made out. The finest specimens found came from beds a mile or more to the northeast of the station, above a coal mine. The fucoids in the sandstone below the coal at Black Buttes are peculiar and instructive. They seem to consist chiefly of *Halymenites major*, which is often weathered out so as to exhibit good specimens, but more frequently these are incased in concretions which attain huge proportions, sometimes having a diameter of six inches. From the ends of these pod-like bodies short sections of the typical fucoid, with its verrucose surface, often project. These inflated concretions vary in shape from cylindrical to globular, and when the projecting fucoid is absent we have the simple spherical concretion which is familiar to all. By careful selection I succeeded in securing a good series of these forms, which seem very clearly to point to the fucoidal origin of this class of concretions.

Point of Rocks has become a familiar name to paleontologists since the discovery there of a thin bed of white sandstone containing very perfectly preserved specimens of fossil plants that proved, upon examination, to constitute a florula somewhat different from that of any other locality in the West. This spot was visited and most of the much discussed forms—*Pistia corrugata*, *Lemna scutata*, *Trapa microphylla*, *Ficus asarifolia*, etc.—were found, but little was added to the previous discoveries of others. This locality is a mile or more east of the station, and is situated quite high up the cliff, which is here steep, and the place is difficult of access. The lower portion of the cliff at most points near the railroad consists of white fucoidal sandstone, the fucoids being in a much less perfect state of preservation than at Black Buttes and more concretionary. Below the fucoidal sandstone, at one point northwest of the station, there occurs a bed of light gray or nearly lavender colored clay containing fragments of ferns and conifers, together with *Pistia corrugata*, *Sequoia biformis*, and other species found in the white sandstone stratum last described. It does not seem possible that this stratum can dip sufficiently to the west to bring it to the base of the bluff, and no evidence of a fault was discovered. The color and fine-grained character of the rock are similar, but the mineral constitution is very different in the two beds, so that the question as to their possible stratigraphical identity is still open. If the fucoidal sandstone forms the base of the Laramie, these clay beds must occupy the summit of the Cretaceous.

Above the massive white sandstone are several coal seams of good quality. They vary in thickness and disappear at some points so as to vary also in number, but about five such seams can usually be seen. Very few dicotyledonous or phenogamous plants exist in the strata between the coal beds, although these resemble those at Black Buttes in all other respects. On the contrary, the fucoids abound throughout all these strata, including those that overlie the highest coal beds.

At one point, nearly opposite the station to the north, a bed was discovered which contained fine specimens of dicotyledonous and other plants. This bed is located just above the lowest coal seam, and is about half way from the base to the summit of the escarpment. The plants seemed, therefore, to occupy a position very similar to those at Black Buttes, and they occur in the same hard gray very arenaceous limestone. They were found only at this one point and in a single layer a foot or more thick, and rocks a few feet distant in either direction were barren of them. This florula proved very interesting and yielded a number of forms not elsewhere found. Among these was the small Ginkgo leaf, which I have called *Ginkgo Laramiensis*.[1] (Plate XXXI, Figure 4.)

Several localities within the Green River group were visited, especially in the vicinity of Green River Station and of Granger, but the description of these will be omitted, and an account given only of localities belonging, with considerable certainty, to the Laramie group as it has been defined. But one other such locality was visited in the year 1881, and respecting the geological position of this there is some doubt. This locality lies very near the boundary line between Wyoming and Utah, some forty miles northwest of Granger, on the divide between the Green and Bear River valleys. The Oregon branch of the Union Pacific Railroad was then in course of construction, and construction trains were running sixteen or eighteen miles out from Granger. The line of the railroad survey was followed from this point, and the plant beds occurred in the ridge through which the tunnel was being excavated. The place was then known as Hodges Pass, and my specimens are so labeled. Fresh-water Tertiary deposits prevailed for the first thirty miles or more, but they were observed to dip perceptibly to the east, and at last disappeared about seven miles east of the divide. They were succeeded here by coal seams, with which they were not conformable, the latter dipping strongly to the northwest. Very heavy beds of coal occur in the vicinity of the pass, and some were reported to have a thickness of sixty feet. The ridge through which the tunnel was being constructed contained fossil plants at nearly all points. The rock consists of a coarse, very arenaceous limestone, or calcareous sandstone, the leaves being either scattered without much stratification through the mass and lying at various angles to one another, often much crumpled or folded, or else in matted layers upon one another in parallel planes, and sometimes so abundant that the rock seems to consist almost wholly of them. In either case it was difficult to obtain perfect specimens. The impressions are very distinct, being of a dark color upon the light matrix, and showing the presence of the silicified leaf-substance. Notwithstanding the coarseness of the material the finer details of nervation are often clearly exhibited. At first sight this flora seemed to be exceedingly monotonous, owing to the prevalence of certain lanceolate or linear willow-shaped forms, but a close study of these reveals considerable variety and the presence of several species and two or three genera. With these, however, occur numerous less abundant forms which lend considerable diversity to the flora of this locality.

There are good reasons for believing that these beds belong to the uppermost series of Laramie strata, and until more is known of them they may be regarded as forming a northern member of the Evanston coal field; the plants, however, differ widely from any found elsewhere.

[1] Science, Vol. V, June 19, 1885, p. 496, fig. 7.

COLLECTIONS FROM THE FORT UNION GROUP.

The several localities from which the principal collections made in the season of 1883 were obtained lie along the Yellowstone River, above and below the town of Glendive, which is situated three miles above old Fort Glendive and on the opposite or right bank of the river, at the point where the Northern Pacific Railroad first enters the valley from the east. Sufficiently precise descriptions of the geographical position of each of these beds were given in my administrative report for that year, and these need not be repeated.

The several beds worked for fossils represent, I am convinced, a number of quite distinct epochs separated far enough in time to have allowed important changes in the vegetation to take place. The localities are not far enough apart geographically to account for the great differences in the different florulas, the extreme distance between the remotest beds not exceeding fifty miles. There were only two of the beds that I was tolerably well satisfied were actually synchronous, and these were among the most remote from each other. These beds are those of Iron Bluff and Burns's Ranch. The plant-bearing stratum at Iron Bluff is situated about fifty feet above the level of the river at low water, while that at Burns's Ranch is at the very water's edge and a few feet above and below. If the beds at Burns's Ranch represent a simple continuation of the strata that appear at Iron Bluff, the dip to the north must be somewhat greater than the natural fall in the river, but the distance is about forty miles. Between Iron Bluff and Glendive, however, there occurs an outcrop of marine Cretaceous strata, containing characteristic Fox Hills shells. This forms an anticlinal of some five or six miles along the right bank of the Yellowstone, and again disappears beneath true Laramie strata some distance above the town. On the side toward Iron Bluff the Cretaceous seems to lie entirely below the railroad cutting at the base of the bluff, but the talus of red blocks of ferruginous baked marl obscured this portion and prevented its study. This is the only outcrop of Cretaceous rocks in the entire district visited by me.

The reasons for regarding the Iron Bluff and Burns's Ranch beds as equivalent are chiefly paleontological. The characteristic plant of the Iron Bluff strata was the large cordate leaf which I have designated as *Cocculus Haydenianus*. This occurs also at Burns's Ranch and has been found only in these two localities. The characteristic plant of the Burns's Ranch locality is *Trapa microphylla*, and this also occurs at Iron Bluff and at no other place in the Fort Union group. The remarkable Cryptogam mentioned above occurs in both beds and several of the celastroid leaves are common to the two localities. None of the forms found at these two localities occur at any of the others. The rock differs greatly in appearance, but this difference is mainly due to the former having been subjected to heat, its carbon driven out, and its iron oxidized, turning it bright red, so that it may be regarded as a ferruginous marl; the other is very calcareous, and may be classed as an argillaceous limestone.

The Iron Bluff stratum yielded a considerable variety of plant forms. Besides the large Cocculus leaves, which were present in great abundance (though, owing to their great size, usually in a fragmentary condition), there occurred an immense quantity of stems of a gigantic Equisetum and of monocotyledonous plants. One of the most striking features of this bed was the occurrence almost everywhere of the stems of certain plants marked all over with very distinct diagonal meshes or cross-lines. These lines consist entirely of deeper colored fine streaks, crossing one another with great regularity at a constant angle. They have the appearance of having wound spirally round the stems in two directions, those of each set being all parallel to one another, and thus forming little rhombs where the systems cross. There is no apparent elevation nor depression, but the fine lines of deeper red are seen in cross-section to penetrate the general surface of light buff, showing that they possess some thickness. The diagonal meshes thus formed vary very much in size, from a millimeter to nearly two centimeters across, and this fineness or coarseness seems to be approximately proportional to the size of the stem on which it occurs. This structure first reminded me of the peculiar cross-lines that occur in the broader stems of certain Monocotyledons, such as Sagittaria, Eriocaulon, etc., and Heer has figured a fossil Sparganium stem exhibiting such a structure. *Caulinites sparganioides* of Lesquereux ("Tertiary Flora," plate xiv, figs. 4 and 10) exhibits something faintly analogous to our plant, and Mr. Lesquereux has sought to explain the occurrence of the cross-lines (p. 100). But the resemblance is too distant to be of any service in the solution of the problem. Certain specimens showing a transition to the normal epidermis, with very fine longitudinal striation, make it next to certain that the parts exhibiting this structure are decorticated, and some evidence exists to prove that the lines may represent the cell walls of the loose cambium tissue of an exogenous plant. The peculiar mode of branching of some specimens also suggests the exogenous rather than the endogenous mode of growth. Certain it is that the diagonal meshes always occur in connection with definite vegetable structure, and even should they prove to be themselves inorganic and to have no connection with the tissues of the plants on which they occur, still the fact must remain that they exist in consequence of such tissues, and are in so far of vegetable origin. I leave the question unsettled for the present and intrust its solution to further research.

The matrix in which the leaf prints found at Burns's Ranch are embedded is an exceedingly fine-grained argillaceous limestone of a bluish-gray color, weathering reddish-brown, and having no regular stratification, but very brittle, and easily breaking at any point with conchoidal fracture, leaving very sharp edges. The degree of friability is much increased by saturation, which was well shown in those fragments that were taken from below the surface of the water in the river. The surfaces of the leaves often form planes of cleavage, and thus many beautiful specimens were obtained, but the tendency to forsake these planes and break out at other places rendered many of the specimens fragmentary. Some very perfect specimens of Trapa were obtained. This plant, as is well known, grows in deep water, from a long submerged stem, which reaches the surface and bears at its summit a cluster of small roundish leaves on petioles of different lengths, which are so arranged upon the stem that all the leaves can lie upon the surface of still water. The longest petioles bear the outer circle of leaves and successively shorter ones those of circles nearer and nearer the center, where the leaves are small and sessile. Several of my specimens as well as some of those collected the year previous by Dr. White show these concentric rosettes of leaves in an interesting way.

The Cocculus leaves are rare in these beds, but several of the best specimens were nevertheless found here. Numerous fine specimens of Populus were obtained, only a few of which are figured for this paper. The sharply serrate, more or less elongated, leaves that seem to belong to the order Celastrineæ were among the most numerous and are nearly or quite all new to science. A few very fine specimens of the remarkable tapeworm-like Cryptogam mentioned above were found here, but this form is not yet figured. The bulbous tufted base is much smaller than in the Iron Bluff specimens, but the remarkable serpent-like rays, with inflated transversely-ribbed heads and finely-toothed middle portion, are shown with great clearness.

These two beds (Iron Bluff and Burns's Ranch) appear to me to form the base of the Fort Union deposit, and present a flora entirely different from that of any other yet discovered. It is remarkable that the Trapa found in both of them appears to be the same species as that found so sparingly in the fine white sandstone layer at Point of Rocks, and what is still more remarkable, I also found at Burns's Ranch a few specimens of the characteristic Point of Rocks plant *Pistia corrugata*. I am inclined to regard these two beds as synchronous, and the differences in the rest of their floras may be accounted for by differences of latitude and the other conditions previously pointed out. Both seem to occupy the base of the Laramie and to overlie the same marine Cretaceous deposit.

In ascending the Yellowstone the next locality is that known as Seven Mile Creek, or Gleason's Ranch. The little stream called Seven Mile Creek, five or six miles above the mouth of which the ranch is located, is situated about seven miles below old Fort Glendive, making it about ten miles below the village of Glendive. Its lower valley is open and shows no exposures, but at Gleason's Ranch it has narrowed, and is bounded by hills that rise on the left bank, by a series of terraces, to a height of about 600 feet. At numerous points along this escarpment good exposures occur, and vegetable remains of one form or another were seen at nearly all elevations. The lowest of the plant beds was not over forty or fifty feet above the valley of the creek, and the plants here consisted almost wholly of the large-leaved Sapindus which is figured on Plate L, Figs. 4–8. A few feet above this occurs a bed of coniferous plants, and immediately above this one yielding a variety of Dicotyledons. Next in order is a stratum of heavy ironstone. This contained a great number of seeds and fruits which are exceedingly curious, but which are as yet wholly undetermined. Mixed with them are leaves in a bad state of preservation belonging to the genus Platanus, and probably to several other genera.

The next bed that proved profitable to work was some 400 feet higher. It was literally filled with leaf impressions, and among these was the immense Platanus leaf, which is here figured natural size, Plate XLI, Fig. 1. Here, too, were found the specimens of Ginkgo, which are also reproduced in our illustrations, and which appear nearly identical with *G. adiantoides* of Unger and quite too near the living plant. Not less interesting was the discovery of the very perfect Sparganium heads, especially those borne on the original stem, one of the specimens of which is shown in the illustrations (Plate XXXII, Fig. 6).

Finally, in the white marl cliff that forms the summit of the series of terraces another florula was found, differing widely from all the rest and characterized by the presence in great abundance of the remarkable leaf which I have called *Credneria daturæfolia* (Plate LVII, Plate LVIII, Figs. 1–5). Associated with this form were many leaves of Populus and Corylus, which were obtained in profusion and in great perfection. This cliff showed evidence of having once been capped by a yellow ferruginous sandstone containing fucoids. One much weatherworn specimen was obtained.

This remarkable series of plant-bearing beds begins at the base with a light-colored and slightly arenaceous limestone, grows less calcareous and more argillaceous and ferruginous until the iron-stone bed is reached. It then presents a series of alternating beds of limestone and ferruginous marl to the Sparganium bed, which is scarcely at all ferruginous. The Credneria cliff consists of a soft, white, and nearly pure marl, slightly tinted on weathered surfaces with iron oxide. The substance of the leaves imbedded in this matrix is clearly visible, and gives the impressions a very dark carbonaceous or lighter brown or lignite-colored appearance.

Judging from the slight northerly dip of the strata from the base of the Laramie below Iron Bluff, where it is seen to rest on the Fox Hills, and from Burns's Ranch, where the lowest strata lie beneath the bed of the river, it seems probable that the summit of the Credneria cliff is from 1,200 to 1,500 feet above the base of the Laramie.

The locality on Clear Creek, fifteen miles above Glendive and about three miles back from the river, yielded the largest quantity of fossil plants, but the flora was more uniform than that of other points and consisted chiefly of Viburnum leaves, which seemed when collected to belong almost entirely to one species, but upon closer study they prove to vary considerably and embrace a number of distinct forms. The other kinds of plants, too, which in comparison seemed very few and meager, prove, when separated from the Viburnum leaves and carefully studied, to be quite numerous and varied. Very large and some quite perfect leaves of *Platanus nobilis*, and of the species that possesses the remarkable basal lobe (*P. basilobata*, Plates XLII and XLIII), occurred here, as well as Ulmus leaves, Equisetum tubers, and Leguminosites fruits. In intimate connection with the abundant Viburnum leaves, and not always easy to distinguish from Equisetum and Leguminosites, there were scattered through the shales, always in single detached form, many ovate or elliptical lanceolate fruits, with deep longitudinal furrows (Plate LXII, Figs. 2–6), which, upon careful comparison, I am convinced are the seeds of the Viburnum. This fact would not possess so great importance were it not that certain leaves apparently identical with the most abundant kind found at Clear Creek had been previously collected from the Fort Union group and referred to a different genus. The discovery of these fruits in such immediate relation to the leaves confirms in a very satisfactory manner the conclusion which I had previously reached and expressed that the leaves published by Dr. Newberry as *Tilia antiqua* belonged really to the genus Viburnum.

Most of the plants collected on Clear Creek came from a single stratum about three feet in thickness, which could be traced for long distances along the cliff on the left bank of the creek valley and within from twenty to fifty feet of its summit. The rocks consist of a limestone shale which is so argillaceous as almost to deserve the name of marl, slightly ferruginous, light gray, and very compact. The layers are quite thick, sometimes almost massive, so that very heavy specimens had to be transported; but at some points a true compact marl occurs, which breaks with ease in both directions and has a conchoidal fracture.

Some nine miles farther up the broad valley of Clear Creek occur some elevated ledges, which were visited. On the top of an isolated butte in this locality a bed of compact marl of very friable character was found, containing leaf impressions. This florula was entirely different from that of the locality farther down, and in fact from any other met with on the Yellowstone. The impressions were very clear, but it was difficult to obtain entire leaves, owing to the ease with which the rock would break across the plane of stratification. It was here that were found the very remarkable digitate Aralia-like leaves figured below (Plate XLVIII, Figs. 10–12, Plate XLIX, Fig. 1). Some of the finest specimens of Corylus also came from this bed, and a peculiar fucoid (*Spi-*

raxis bivalvis, Plate XXXI, Fig. 3) was abundant, having spiral striations, as if twisted. This fucoid always exhibited a tendency to split open longitudinally into two equal valves, and many of the segments lay around in halves, the plane of division being always smooth and even and passing directly through the center of the specimen. Only a small collection was made at this point.

The characteristic fossil of the Cracker Box Creek beds was a species (or two very closely related species) of Viburnum (*V. asperum*, Newby., Plate LXIV, Figs. 4–9, *V. Newberrianum*, Plate LXIV, Figs. 10–12, Plate LXV, Figs. 1–3), which, however, differs very much from the abundant forms of Clear Creek and does not occur there, nor does the Clear Creek form occur at Cracker Box Creek, although the two localities are only five miles apart and very similarly situated. On the right bank of the valley occurred beds containing Populus leaves, masses of *Taxodium Europæum*, not elsewhere met with, and an abundance of both Equisetum and cane (Arundo?), the latter very large. On the left bank occurred the principal Viburnum bed, and in this a few other plants were found.

The rock in which the specimens from this locality were embedded is a highly calcareous marl, sometimes amounting to argillaceous limestone and slightly ferruginous. At certain points it is of a dark blue color, sometimes nearly black, and in one fossiliferous bed the outer portion of a small *butte* which was cut through by a gulch was of a red color, like that of Iron Bluff, while the interior was blue or dark. This was of course due to combustion of the carbonaceous matter, the effect of which had not penetrated to the center of the butte. This combustion did not affect the character of the plant impressions, but the unburned portion was much more easily worked and much heavier. In a few of the oxidized buff specimens from this place, the peculiar diagonal marking, so striking at Iron Bluff, appears. It seems in these cases to occur on the large gramineous culms.

The several localities on the Yellowstone River above described were all visited by Dr. C. A. White and his party the year previous, and their stratigraphical position determined; but, nevertheless, wherever it was possible I observed and collected the molluscan forms, which, however, were very rare. The following shells accompany my collections and have been kindly named for me by Dr. White:

From Iron Bluff: Sphærium (planum?); Physa (Canadensis?).

From Burns's Ranch: Acroloxus minutus.

From Seven Mile Creek: Ironstone bed: Viviparus (species indeterminable); Unio (species indeterminable); scale of a gar. Sparganium bed: Sphærium (species indeterminable).

From Clear Creek: Physa Canadensis, Whiteaves, ined.: Helix (Patula) (species undescribed).

From Cracker Box Creek: Viviparus prudentius, White; fragments of gasteropods.

Very few fossil plants were collected during the journey that was made in August and September down the Missouri River from Fort Benton to Bismarck; but observations that were made upon the Laramie strata as seen at different points, and upon the vegetable remains found in them during that journey, may fittingly be recorded here.

This formation was first met with as the Judith River group, near Birch Creek, about 100 miles below Fort Benton. It here presented the massive sandstone stratum at its base similar to that of the Bitter Creek deposits and appeared about 600 feet above the river, resting upon the Cretaceous. Above this sandstone a few plant remains were found in a soft, whitish-gray marl bed, too imperfect for specific identification, but showing the presence of Equisetum and coniferous and monocotyledonous plants.

Before reaching this point, and much of the way from Coal Banks, an extensive system of dikes of micaceous basalt was observed cutting through the white Cretaceous sandstone in all directions and forming picturesque objects along the river. These seemed to disappear as the Judith River beds came into view, leaving the question of their age relative to that of these beds unsettled; but at a point 18 miles below Claggett a single one of these dikes was observed to rise entirely through the Cretaceous and Laramie strata, both of which were here exposed, thus proving conclusively that the upthrow of lava which produced these dikes occurred posterior to the deposit of at least a large portion of the Judith River strata.

From a point about fifteen miles below Grand Island, where the Judith River group may be said to end, to the Muscle Shell, where the Fort Union group proper may be said to begin, no Laramie strata can be seen, and for much of the distance from the mouth of the Muscle Shell to Poplar Creek, 100 miles above the mouth of the Yellowstone, they merely cap the hills or are wanting altogether. Below Poplar Creek they come down to the level of the river, and some twenty or thirty miles below that point fossil plants were found, including Populus and other Dicotyledons, as well as Conifers, at three different horizons in the cliffs on the right bank of the river. At other points between this and Fort Union, stems of cane and Equisetum were common, but no rich plant beds were found. The Laramie hills here often form nearly perpendicular walls along the south bank of the river and thick beds of coal may be traced for great distances. Much of the Carbonaceous rock has been burned; and at one point the fire was still burning, the rocks in the vicinity of a smoking crevasse being hot, but no actual ignition being visible from without. The progress of this combustion could often be easily traced along a vertical escarpment and the lines clearly seen which were formed by its cessation. At one place the transition from brick-red to dark slate color was abrupt along a vertical line extending from top to bottom of a wall several hundred feet high, forming a very striking contrast.

At a point about thirty miles below Fort Buford an interesting bed of northern drift was observed, forming a layer about two feet thick, close down to the water's edge. One hundred miles below Fort Buford a fine deposit of typical Fort Union plants was found, the light slate-colored marl containing them being, however, quite soft. At Little Knife Creek another bed was examined. The Fort Union group is the only deposit in view throughout all this region. Plants were seen at nearly all points that were examined, and at Fort Stevenson I visited a range of low red buttes three miles east of the fort, where I collected a number of good specimens. They closely resembled the forms of the Lower Yellowstone and those previously described from various points within the Fort Union group.

Below this point the country is more flat, the hills are lower and more distant from the river, and there is evidence that the Laramie deposits are passing below the surface. Square Butte, eight or nine miles above Bismarck, is capped by strata that appear to occupy the summit of the formation.

LIST OF SPECIES ILLUSTRATED.

The proportions which this paper has assumed preclude any explanatory remarks upon the figures which I have selected to illustrate the recent collections above described from the Laramie group, and all that can be added in explanation of them is a simple list of the names of the species as they have been decided upon up to this time, leaving more ample discussion of the nice points involved, and the statement of the evidence for or against these determinations, for a subsequent publication. This effort must be regarded as tentative, and subject to much alteration as more thorough study of all the material in hand shall throw additional light upon the many knotty problems involved.

CRYPTOGAMS.

Fucus lignitum, Lx. Plate XXXI, Figs. 1, 2.

Point of Rocks, Wyoming; white sandstone bed east of station (Fig. 1). Burns's Ranch, Montana (Fig. 2).

Spiraxis bivalvis, n. sp. Plate XXXI, Fig. 3.

Head of Clear Creek, Montana.

CONIFERÆ.

Ginkgo Laramiensis, Ward, Science, Vol. V, June 19, 1885, p. 496, fig. 7. Plate XXXI, Fig. 4.

Point of Rocks, Wyoming; gray sandstone bed north of station.

Ginkgo adiantoides, Ung. Plate XXXI, Figs. 5, 6.

Seven Mile Creek, Montana; Sparganium bed.

Sequoia biformis, Lx. Plate XXXI, Figs. 7–12.

Point of Rocks, Wyoming; white sandstone bed east of station (Figs. 7, 8); white marl bed northwest of station (Figs. 9–12).

MONOCOTYLEDONS.

Phragmites Alaskana, Heer. Plate XXXII, Figs. 1–3.

Burns's Ranch, Montana.

Lemna scutata, Dawson. Plate XXXII, Figs. 4, 5.

Burns's Ranch, Montana.

Sparganium Stygium, Heer. Plate XXXII, Figs. 6, 7.

Seven Mile Creek, Montana.

DICOTYLEDONS.

Populus glandulifera, Heer. Plate XXXIII, Figs. 1–4. Fig. *3a*, enlarged.

Burns's Ranch, Montana.

Populus cuneata, Newby. Plate XXXIII, Figs. 5–11.

Seven Mile Creek, Montana; Sparganium bed (Figs. 5–10). Clear Creek, Montana (Fig. 11).

Populus speciosa, n. sp. Plate XXXIV, Figs. 1–4.

Clear Creek, Montana.

Populus amblyrhyncha, n. sp. Plate XXXIV, Figs. 5–9; Plate XXXV, Figs. 1–6.

Seven Mile Creek, Montana; white marl bed.

Populus daphnogenoides, n. sp. Plate XXXV, Figs. 7–9.

Seven Mile Creek, Montana; white marl bed.

Populus oxyrhyncha, n. sp. Plate XXXV, Figs. 10, 11.

Seven Mile Creek, Montana; white marl bed.

Populus craspedodroma, n. sp. Plate XXXVI, Fig. 1.

Burns's Ranch, Montana.

Populus Whitei, n. sp. Plate XXXVI, Fig. 2.

Burns's Ranch, Montana; collected by Dr. C. A. White in 1882 and named in his honor.

Populus hederoides, n. sp. Plate XXXVI, Fig. 3.

Seven Mile Creek, Montana; white marl bed.

Populus Richardsoni, Heer. Plate XXXVI, Fig. 4.

Burns's Ranch, Montana.

Populus anomala, n. sp. Plate XXXVI, Fig. 5.

Burns's Ranch, Montana.

Populus Grewiopsis, n. sp. Plate XXXVI, Fig. 6.

Seven Mile Creek, Montana; white marl bed.

Populus inæqualis, n. sp. Plate XXXVI, Fig. 7.

Burns's Ranch, Montana.

Quercus bicornis, n. sp. Plate XXXVI, Fig. 8.

Seven Mile Creek, Montana; bed below the ironstone.

Quercus Doljensis, Pilar. Plate XXXVI, Figs. 9, 10.

Black Buttes Station, Wyoming.

Quercus Carbonensis, n. sp. Plate XXXVII, Fig. 1.

Carbon Station, Wyoming.

Quercus Dentoni, Lx. Plate XXXVII, Fig. 2.

Point of Rocks, Wyoming; gray sandstone bed north of station.

Dryophyllum aquamarum, n. sp. Plate XXXVII, Figs 3–5.

Black Buttes Station, Wyoming.

Dryophyllum Bruneri, n. sp. Plate XXXVII, Figs. 6–9.

Point of Rocks, Wyoming; gray sandstone bed (Figs. 6, 7). Hodges Pass, Wyoming (Figs. 8, 9). Named in honor of Prof. Lawrence Bruner.[1]

Dryophyllum falcatum, n. sp. Plate XXXVII, Fig. 10.

Hodges Pass, Wyoming.

Dryophyllum basidentatum, n. sp. Plate XXXVII, Fig. 11.

Carbon Station, Wyoming.

Corylus Americana, Walt. Plate XXXVIII, Figs. 1–5.

Seven Mile Creek, Montana; white marl bed.

Corylus rostrata, Ait. Plate XXXIX, Figs. 1–4.

Seven Mile Creek, Montana; white marl bed.

Corylus Fosteri, n. sp. Plate XXXIX, Figs. 5, 6.

Head of Clear Creek, Montana (Fig. 5); Clear Creek, Montana (Fig. 6); the latter collected in 1882 by Dr. White's party; the first by Mr. Richard Foster, for whom it is named.

? *Corylus McQuarrii*, Heer. Plate XXXIX, Fig. 7.

Seven Mile Creek, Montana; bed below the ironstone.

Alnus Grewiopsis, n. sp. Plate XXXIX, Fig. 8.

Hodges Pass, Wyoming.

Betula prisca, Ett. Plate XL, Fig. 1.

Seven Mile Creek, Montana; bed below the ironstone.

Betula coryloides, n. sp. Plate XL, Fig. 2.

Seven Mile Creek, Montana; white marl bed.

B tula basiserrata, n. sp. Plate XL, Fig. 3.

Seven Mile Creek, Montana; white marl bed.

Myrica Torreyi, Lx. Plate XL, Fig. 4.

Black Buttes Station, Wyoming.

? *Juglans Ungeri*, Heer. Plate XL, Fig. 5.

Burns's Ranch, Montana.

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[1] Professor Bruner's valuable services on this expedition are otherwise acknowledged in my administrative report for that year. (See Third Annual Report United States Geological Survey, 1881–'82, p. 29).

Juglans nigella, Heer. Plate XL, Fig. 6.

Burns's Ranch, Montana.

Carya antiquorum, Newby. Plate XL, Fig. 7.

Carbon Station, Wyoming.

Platanus Heerii, Lx. Plate XL, Figs. 8, 9.

Black Buttes Station, Wyoming.

Platanus nobilis, Newby. Plate XLI, Fig. 1.

Seven Mile Creek, Montana; Sparganium bed.

Platanus basilobata, n. sp. Plate XLII, Figs. 1–4. Fig. 4*a*, enlarged. Plate XLIII, Fig. 1.

Seven Mile Creek, Montana; Sparganium bed (Plate XLII). Clear Creek, Montana (Plate XLIII).

Platanus Guillelmæ, Göpp. Plate XLIV, Fig. 1.

Burns's Ranch, Montana.

Platanus Raynoldsii, Newby. Plate XLIV, Figs. 2, 3.

Clear Creek, Montana; collected in 1882 by Dr. White's party.

Ficus irregularis, Lx. Plate XLIV, Figs. 4, 5.

Golden, Colorado.

Ficus spectabilis, Lx. Plate XLIV, Fig. 6.

Golden, Colorado; collected in November, 1881, by Mr. C. W. Cross for Mr. S. F. Emmons.

Ficus Crossii, n. sp. Plate XLIV, Fig. 7.

Golden, Colorado; collected in 1881 by Mr. C. W. Cross for Mr. S. F. Emmons.

Ficus speciosissima, n. sp. Plate XLV, Fig. 1.

Point of Rocks, Wyoming; gray sandstone bed north of station.

Ficus tiliæfolia, Heer. Plate XLV, Fig. 2.

Burns's Ranch, Wyoming.

Ficus sinuosa, n. sp. Plate XLV, Fig. 3.

Black Buttes Station, Wyoming.

Ficus limpida, n. sp. Plate XLV, Fig. 4.

Clear Creek, Montana.

Ficus viburnifolia, n. sp. Plate XLV, Figs. 5–9.

Clear Creek, Montana.

Ulmus planeroides, n. sp. Plate XLVI, Figs. 1, 2.

Clear Creek, Montana.

Ulmus minima, n. sp. Plate XLVI, Figs. 3, 4.

Clear Creek, Montana.

Ulmus rhamnifolia, n. sp. Plate XLVI, Fig. 5.

Clear Creek, Montana.

Ulmus orbicularis, n. sp. Plate XLVI, Fig. 6.

Clear Creek, Montana.

Laurus resurgens, Sap. Plate XLVI, Fig. 7.

Bull Mountains, Montana; collected by Dr. A. C. Peale in 1883.

Laurus primigenia, Ung. Plate XLVI, Figs. 8–10.

Carbon Station, Wyoming (Fig. 8). Point of Rocks, Wyoming; white sandstone bed east of station (Figs. 9, 10).

Litsæa Carbonensis, n. sp. Plate XLVI, Fig. 11.

Carbon Station, Wyoming.

Cinnamomum lanceolatum, Heer. Plate XLVI, Fig. 12.

Hodges Pass, Wyoming.

Cinnamomum affine, Lx. Plate XLVII, Figs. 1-3.

Black Buttes Station, Wyoming.

Daphnogene elegans, Wat. Plate XLVII, Fig. 4.

Black Buttes Station, Wyoming.

? *Monimiopsis amboræfolia*, Sap. Plate XLVII, Fig. 5.

Seven Mile Creek, Montana; Sapindus bed.

? *Monimiopsis fraterna*, Sap. Plate XLVII, Fig. 6.

Seven Mile Creek, Montana; bed below the ironstone.

Nyssa Buddiana, n. sp. Plate XLVII, Fig. 7.

Hodges Pass, Wyoming. Named in honor of Mr. J. Budd, superintendent of construction of the Oregon branch of the Union Pacific Railroad, who directed me to this locality.

Cornus Fosteri, n. sp. Plate XLVII, Fig. 8.

Upper Seven Mile Creek, ten miles above Glendive, Montana; collected by Mr. Richard Foster, of Dr. White's party, in 1882.

Cornus Studeri, Heer. Plate XLVIII, Fig. 1.

Point of Rocks, Wyoming; gray sandstone bed north of station.

Cornus Emmonsii, n. sp. Plate XLVIII, Figs. 2, 3.

Golden, Colorado (Fig. 2); collected by Mr. S. F. Emmons, in July, 1882. Point of Rocks, Wyoming; gray sandstone bed north of station (Fig. 3).

Hedera parvula, n. sp. Plate XLVIII, Fig. 4.

Clear Creek, Montana.

Hedera minima, n. sp. Plate XLVIII, Fig. 5.

Head of Clear Creek, Montana.

Hedera Bruneri, n. sp. Plate XLVIII, Fig. 6.

Black Buttes Station, Wyoming.

Hedera aquamara, n. sp. Plate XLVIII, Fig. 7.

Black Buttes Station, Wyoming.

Aralia notata, Lx. Plate XLVIII, Fig. 8.

Clear Creek, Montana.

Aralia Looziana, Sap. & Mar. Plate XLVIII, Fig. 9.
Clear Creek, Montana.

Aralia digitata, n. sp. Plate XLVIII, Figs. 10–12; Plate XLIX, Fig. 1.
Head of Clear Creek, Montana.

Trapa microphylla, Lx. Plate XLIX, Figs. 2–5.
Burns's Ranch, Wyoming.

Hamamelites fothergilloides, Sap. Plate XLIX, Fig. 6.
Seven Mile Creek, Montana; bed below the ironstone.

Leguminosites arachioides, Lx. Plate XLIX, Fig. 7.
Clear Creek, Montana.

Acer trilobatum tricuspidatum, Heer. Plate XLIX, Figs. 8, 9.
Clear Creek, Montana (Fig. 8); collected by Dr. White's party in 1882. Little Missouri River, Dakota (Fig. 9); collected by Hayden and Peale in 1883.

Acer indivisum, Web. Plate L, Fig. 1.
Carbon Station, Wyoming.

Sapindus affinis, Newby. Plate L, Figs. 2, 3.
Gladstone, Dakota; collected by Hayden and Peale in 1883.

Sapindus grandifoliolus, n. sp. Plate L, Figs. 4–8.
Seven Mile Creek, Montana; Sapindus bed.

Sapindus alatus, n. sp. Plate L, Figs. 9, 10.
Seven Mile Creek, Montana; Sapindus bed.

Sapindus angustifolius, Lx. Plate LI, Figs. 1–3.
Seven Mile Creek, Montana; Sapindus bed.

Vitis Bruneri, n. sp. Plate LI, Figs. 4, 5.
Carbon Station, Wyoming.

Vitis Carbonensis, n. sp. Plate LI, Fig. 6.
Carbon Station, Wyoming.

Vitis Xantholithensis, n. sp. Plate LI, Figs. 7, 8.
Burns's Ranch, Montana.

Vitis cuspidata, n. sp. Plate LI, Figs. 9–11.
Burns's Ranch, Montana.

Berchemia multinervis, Al. Br. Plate LI, Figs. 12, 13.
Golden, Colorado.

Zizyphus serrulata, n. sp. Plate LI, Figs. 14, 15.
Burns's Ranch, Montana.

Zizyphus Meekii, Lx. Plate LII, Figs. 1, 2.
Carbon Station, Wyoming (Fig. 1). Bozeman Coal Mines, Montana (Fig. 2); collected by Hayden and Peale in 1883.

Zizyphus cinnamomoides, Lx. Plate LII, Fig. 3.
Seven Mile Creek, Montana; white marl bed.

Paliurus Colombi, Heer. Plate LII, Figs. 4–6.
Burns's Ranch, Montana (Figs. 4, 5). Carbon Station, Wyoming (Fig. 6).

Paliurus pulcherrima, n. sp. Plate LII, Fig. 7.
Carbon Station, Wyoming.

Paliurus Pealei, n. sp. Plate LII, Figs. 8–10.
Little Missouri River, Dakota; collected by Dr. A. C. Peale in 1883.

Celastrus ferrugineus, n. sp. Plate LII, Figs. 11–14.
Burns's Ranch, Montana (Fig. 11); Iron Bluff, Montana (Figs. 12–14).

Celastrus Taurinensis, n. sp. Plate LII, Figs. 15, 16.
Bull Mountains, Montana (Figs. 15); Burns's Ranch, Montana (Fig. 16).

Celastrus alnifolius, n. sp. Plate LIII, Figs. 1, 2.
Burns's Ranch, Montana.

Celastrus pterospermoides, n. sp. Plate LIII, Figs. 3–6.
Burns's Ranch, Montana.

Celastrus ovatus, n. sp. Plate LIII, Fig. 7.
Iron Bluff, Montana.

Celastrus grewiopsis, n. sp. Plate LIII, Fig. 8.
Burns's Ranch, Montana.

Celastrus curvinervis, n. sp. Plate LIII, Figs. 9, 10.
Burns's Ranch, Montana.

Euonymus Xantholithensis, n. sp. Plate LIV, Figs. 1, 2.
Burns's Ranch, Montana.

Elæodendron serrulatum, n. sp. Plate LIV, Figs. 3–5.
Burns's Ranch, Montana (Figs. 3, 4). Seven Mile Creek, Montana (Fig. 5).

Elæodendron polymorphum, n. sp. Plate LIV, Figs. 6–12.
Burns's Ranch, Montana.

Grewia crenata (Ung.) Heer. Plate LIV, Fig. 13.
Bull Mountains, Montana; collected by Hayden and Peale in 1883.

Grewia celastroides, n. sp. Plate LIV, Fig. 14.
Iron Bluff, Montana.

Grewia Pealei, n. sp. Plate LV, Figs. 1–3.
Bull Mountains, Montana; collected by Dr. A. C. Peale in 1883.

Grewia obovata, Heer. Plate LV, Figs. 4, 5.
Seven Mile Creek, Montana; white marl bed.

Grewiopsis platanifolia, n. sp. Plate LV, Fig. 6.
Seven Mile Creek, Montana; Sparganium bed.

Grewiopsis viburnifolia, n. sp. Plate LV, Fig. 7.
Burns's Ranch, Montana.

Grewiopsis populifolia, n. sp. Plate LV, Figs. 8–10.

Burns's Ranch, Montana.

Grewiopsis ficifolia, n. sp. Plate LVI, Figs. 1, 2.

Black Buttes Station, Wyoming.

Grewiopsis paliurifolia, n. sp. Plate LVI, Fig. 3.

Black Buttes Station, Wyoming.

Pterospermites cordatus, n. sp. Plate LVI, Fig. 4.

Seven Mile Creek, Montana; bed below the ironstone.

Pterospermites Whitei, n. sp. Plate LVI, Figs. 5, 6.

Burns's Ranch, Montana; collected by Dr. C. A. White in 1882.

Pterospermites minor, n. sp. Plate LVI, Figs. 7–9.

Burns's Ranch, Montana.

Credneria? daturæfolia, n. sp. Plate LVII, Figs. 1–5; Plate LVIII, Figs. 1–5.

Seven Mile Creek, Montana; white marl bed.

Plate LVIII, Fig. 6, represents a leaf of Datura Stramonium, L., introduced to illustrate the similarity of its nervation to that of the fossil leaves.

Cocculus Haydenianus, n. sp. Plate LIX, Figs. 1–5.

Burns's Ranch, Montana (Figs. 1–4). Iron Bluff, Montana (Fig. 5).

Named in honor of Ensign Everett Hayden, U. S. N., who has taken a special interest in this plant.

Liriodendron Laramiense, n. sp. Plate LX, Fig. 1.

Point of Rocks Station, Wyoming; gray sandstone bed north of station.

Magnolia pulchra, n. sp. Plate LX, Figs. 2, 3.

Point of Rocks Station, Wyoming; gray sandstone bed north of station.

Diospyros brachysepala, Al. Br. Plate LX, Figs. 4, 5.

Burns's Ranch, Montana (Fig. 4). Seven Mile Creek, Montana (Fig. 5).

Diospyros ficoidea, Lx. Plate LX, Figs. 6, 7.

Burns's Ranch, Montana (Fig. 6). Clear Creek, Montana (Fig. 7).

Diospyros ? obtusata, n. sp. Plate LX, Fig. 8.

Seven Mile Creek, Montana; bed below the ironstone.

Viburnum tilioides (*Tilia antiqua*, Newby.). Plate LXI, Figs. 1–7; Plate LXII, Figs. 1–6.

Clear Creek, Montana.

Viburnum perfectum, n. sp. Plate LXII, Figs. 7–9.

Clear Creek, Montana.

Viburnum macrodontum, n. sp. Plate LXII, Fig. 10.

Clear Creek, Montana.

Viburnum limpidum, n. sp. Plate LXIII, Figs. 1–4.

Clear Creek, Montana.

Viburnum Whymperi, Heer. Plate LXIII, Fig. 5.

Clear Creek, Montana.

Viburnum perplexum, n. sp. Plate LXIII, Figs. 6, 7.

Burns's Ranch, Montana; collected by Dr. White's party in 1882.

Viburnum elongatum, n. sp. Plate LXIII, Figs. 8, 9.

Clear Creek, Montana.

Viburnum oppositinerve, n. sp. Plate LXIV, Figs. 1, 2.

Clear Creek, Montana.

Viburnum erectum, n. sp. Plate LXIV, Fig. 3.

Clear Creek, Montana.

Viburnum asperum, Newby. Plate LXIV, Figs. 4–9.

Cracker Box Creek, Montana (Figs. 4–8). Seven Mile Creek, Montana; Sparganium bed (Fig. 9).

Viburnum Newberrianum, n. sp. Plate LXIV, Figs. 10–12; Plate LXV, Figs. 1–3.

Cracker Box Creek, Montana.

Viburnum Nordenskjöldi, Heer. Plate LXV, Figs. 4–6.

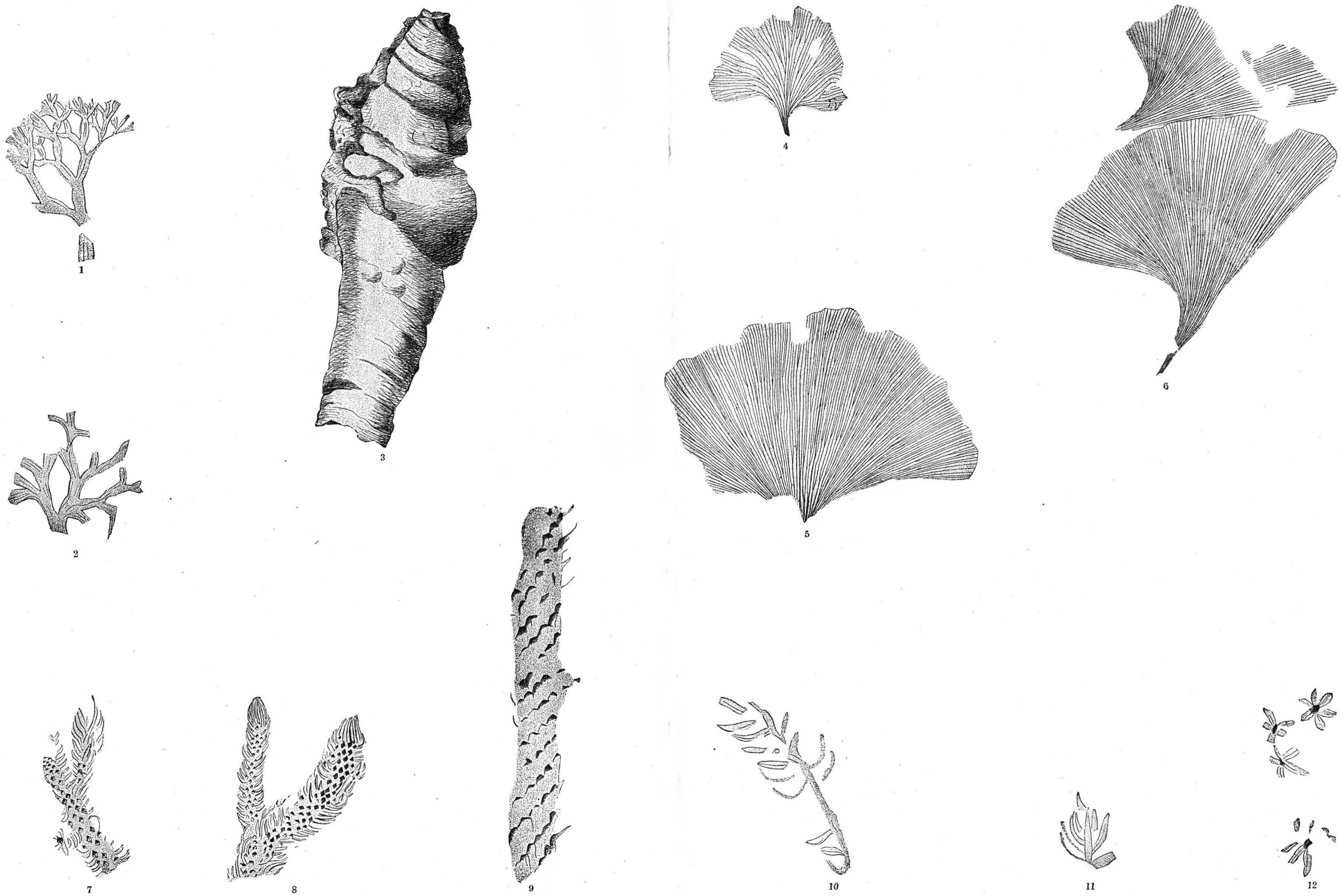
Clear Creek, Montana (Fig. 4). Little Missouri River, Dakota (Fig. 6). Gladstone, Dakota, (Fig. 5). The last two were collected by Dr. A. C. Peale in 1883.

Viburnum betulæfolium, n. sp. Plate LXV, Fig 7.

Burns's Ranch, Montana; collected by Dr. White's party in 1882.

Viburnum finale, n. sp. Plate LXV, Fig 8.

Iron Bluff, Montana.



CRYPTOGAMS.

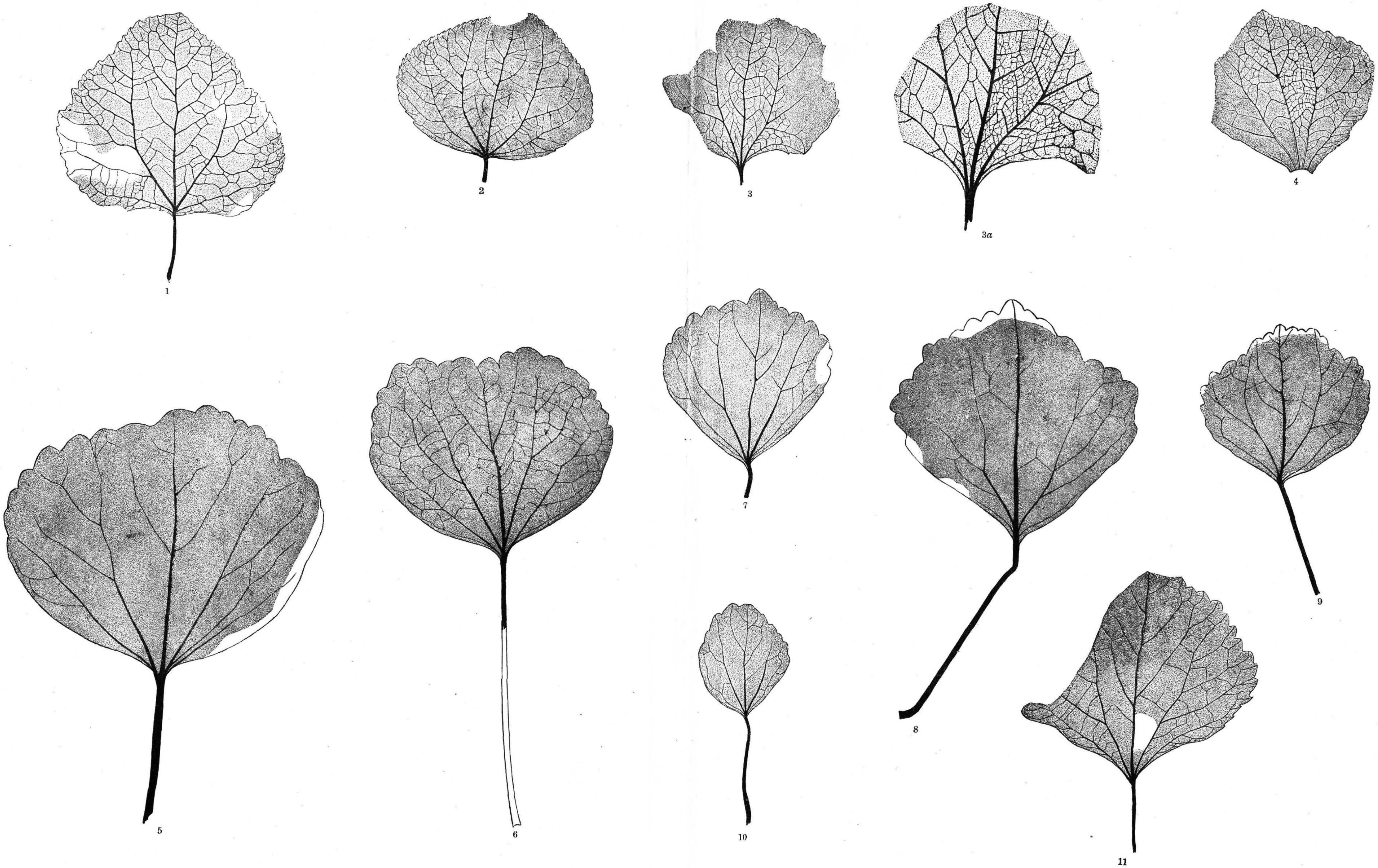
FIGS. 1, 2. Fucus lignitum, Lx. FIG 3. Spiraxis bivalvis, n. sp.

CONIFERÆ.

FIG. 4. Ginkgo Laramiensis, Ward. FIGS. 5, 6. G. adiantoides, Ung FIGS. 7–12. Sequoia biformis, Lx.

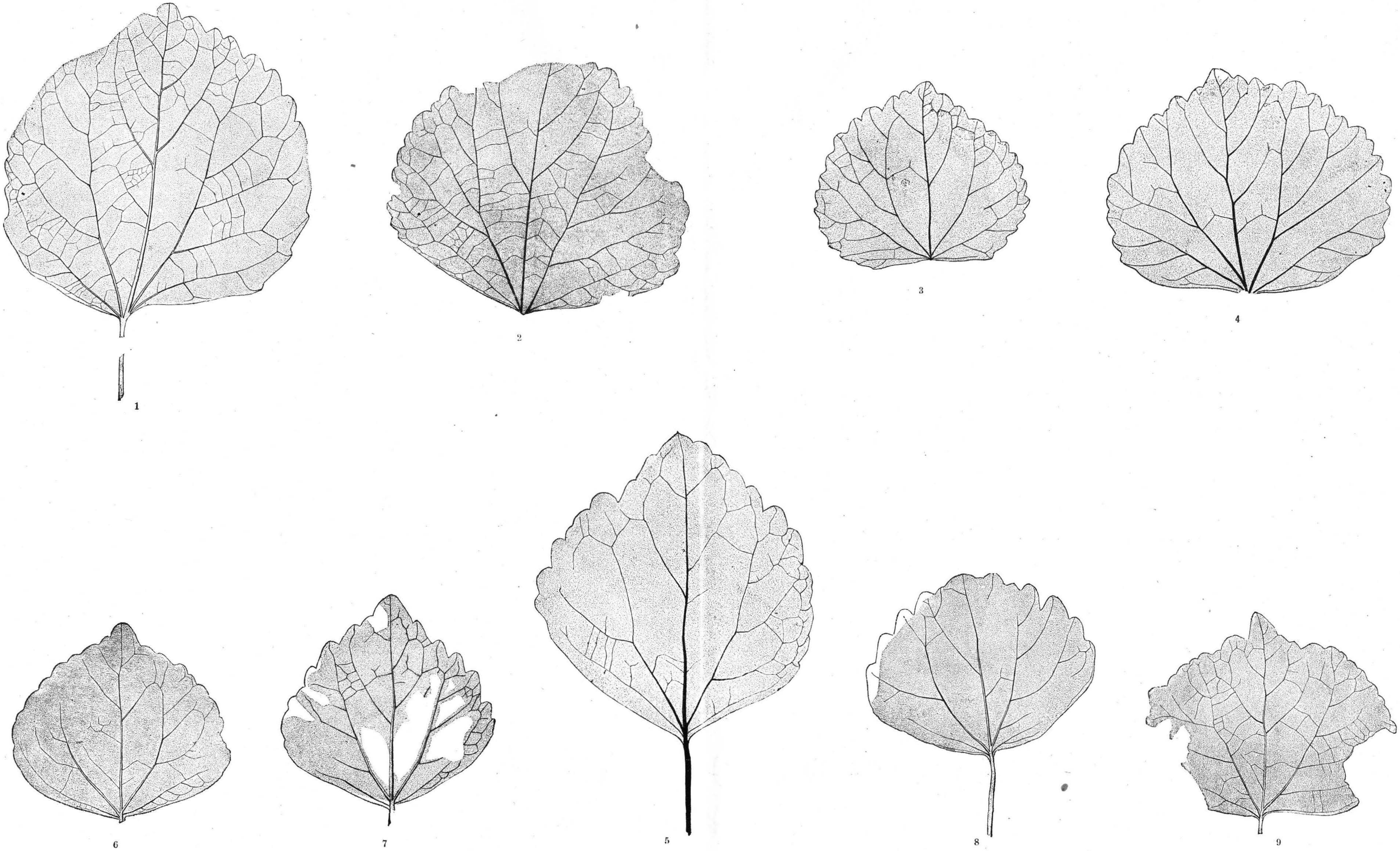
MONOCOTYLEDONS.

FIGS. 1-3. Phragmites Alaskana, Heer. FIGS. 4, 5. Lemna scutata, Dawson. FIGS. 6, 7. Sparganium Stygium, Heer.



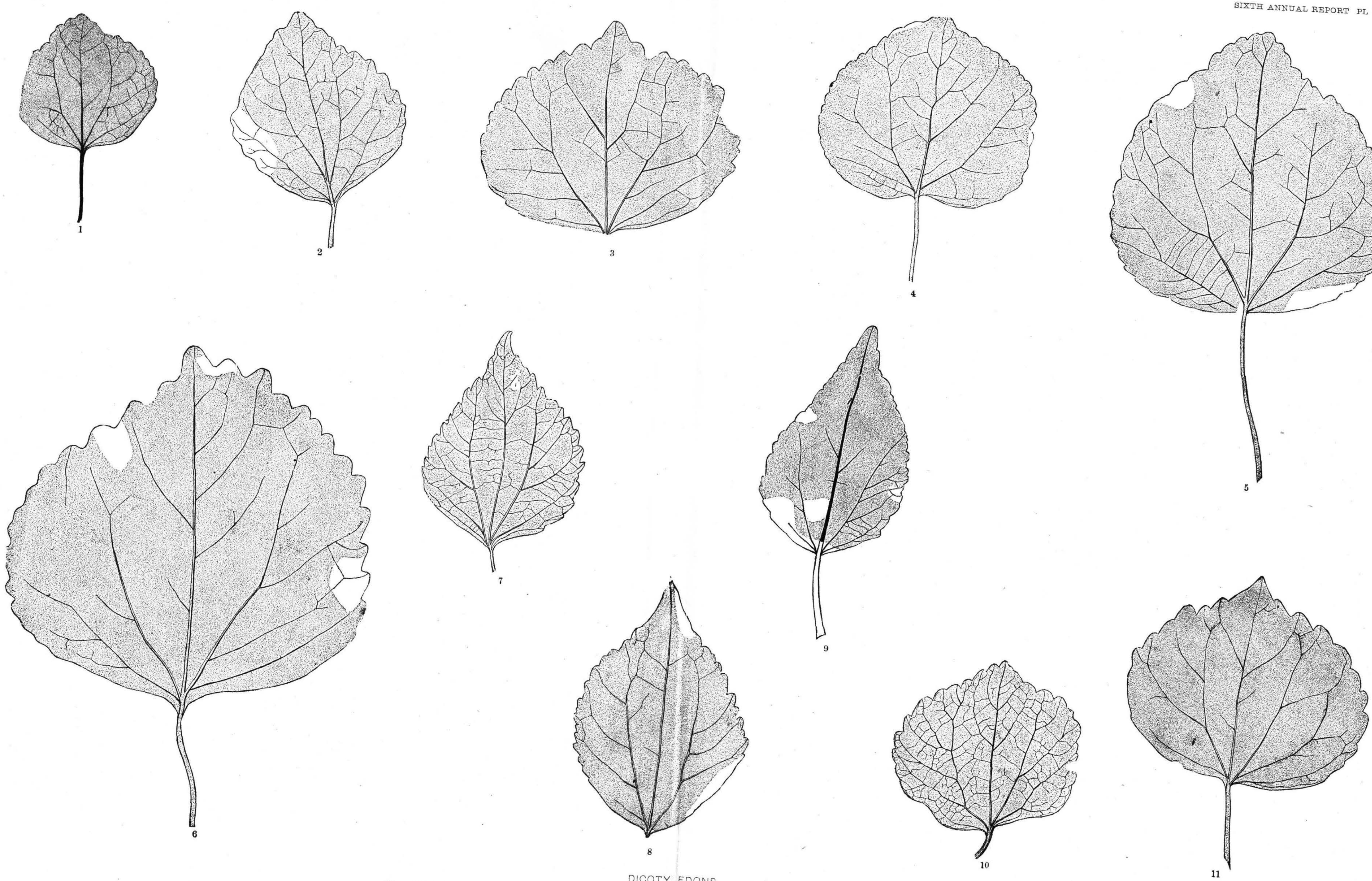
DICOTYLEDONS.

FIGS. 1-4 Populus glandulifera, Heer. FIG. 3a. Enlarged detail of Fig. 3. FIGS. 5-11. P. cuneata, Newby.



DICOTYLEDONS.

FIGS. 1-4. Populus speciosa, n. sp. FIGS. 5-9. P. amblyrhyncha, n. sp.



DICOTYLEDONS.

Figs. 1-6. Populus amblyrhyncha, n. sp. **Figs. 7-9. P. daphnogenoides, n. sp.** **Figs. 10, 11. P. oxyrhyncha. n. sp.**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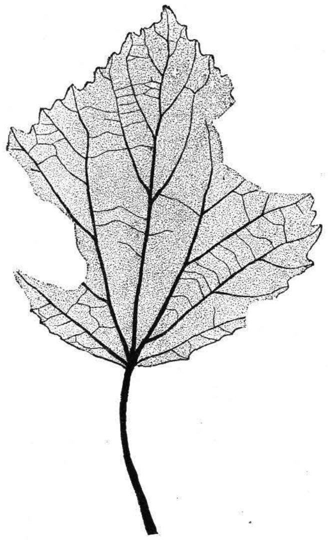
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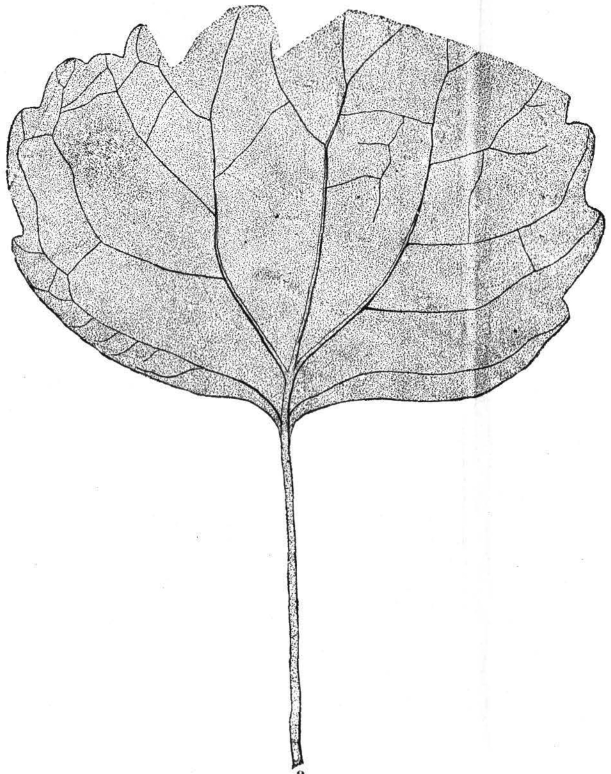
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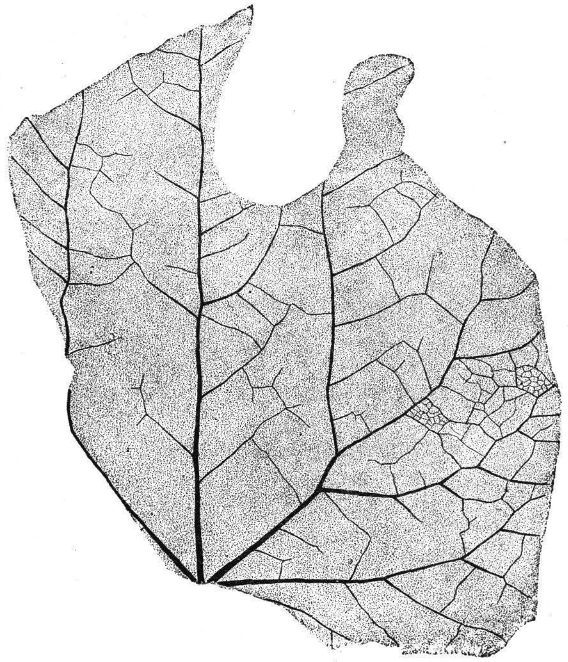
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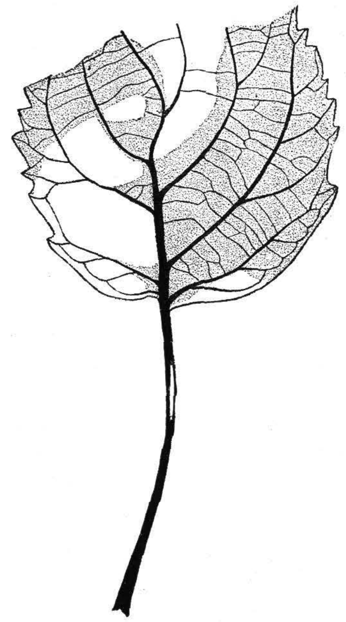
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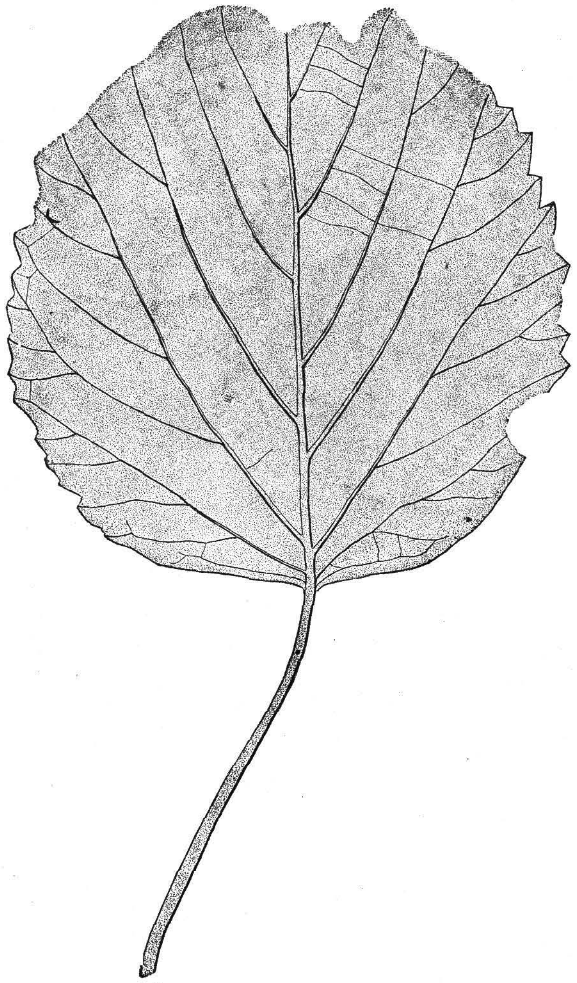
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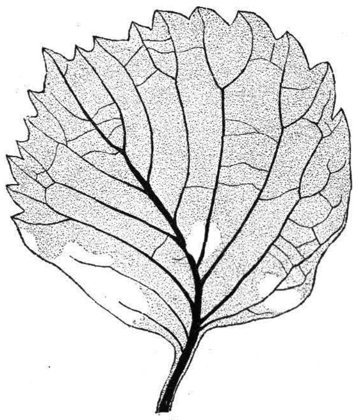
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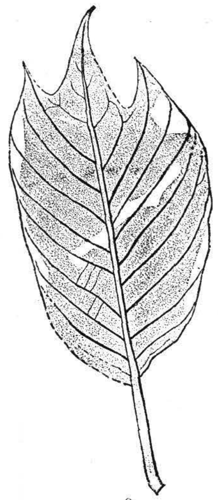
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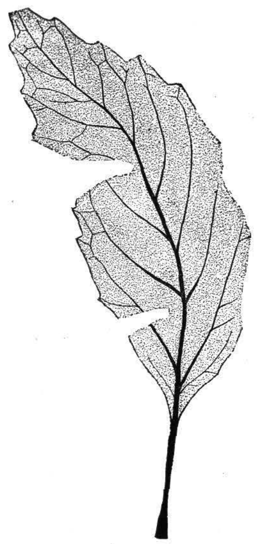
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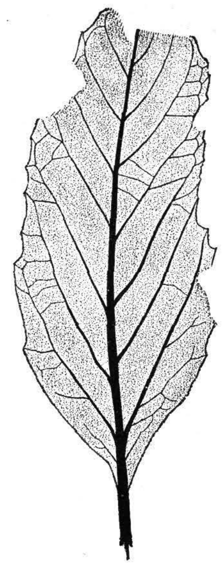
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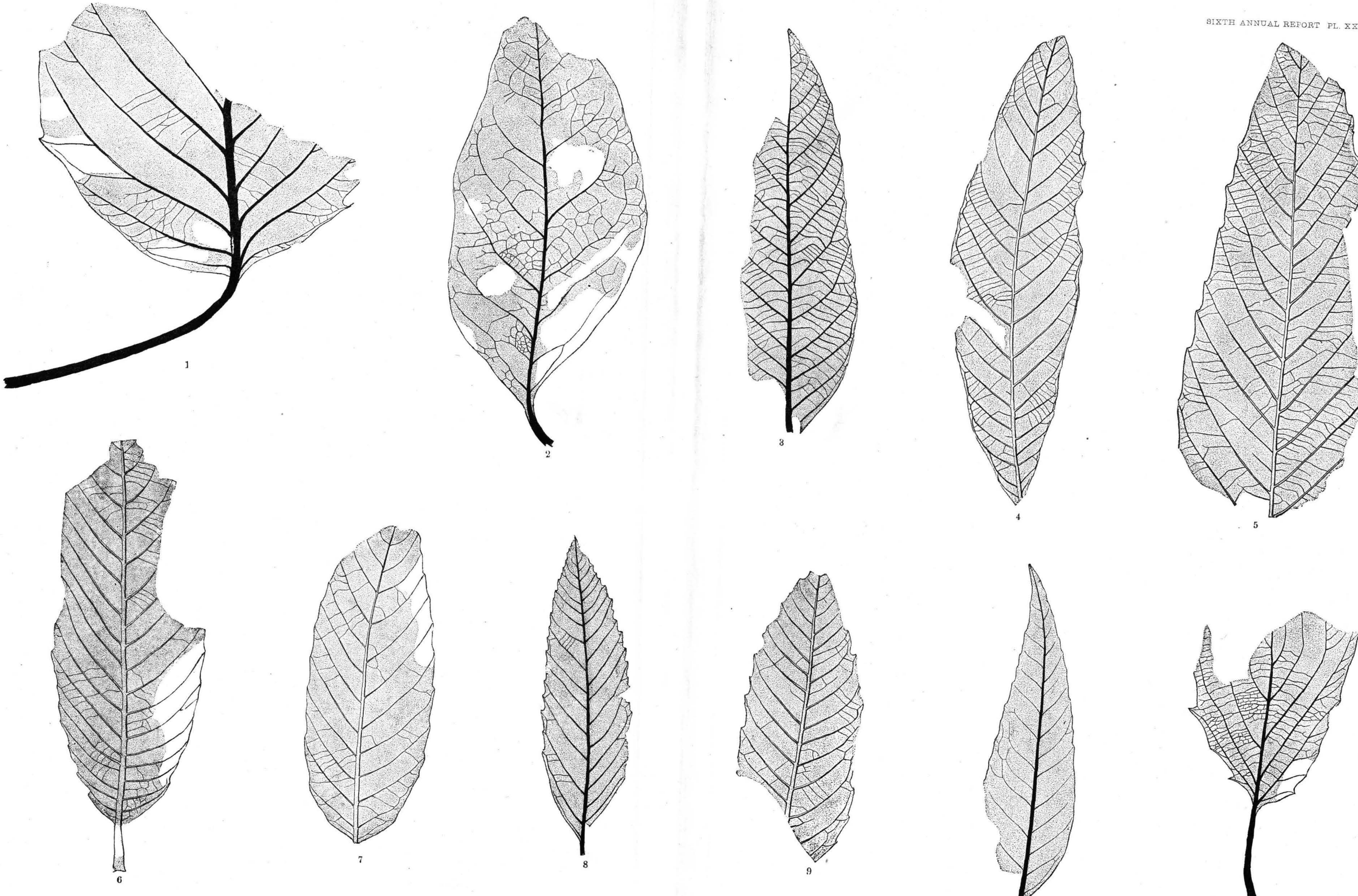
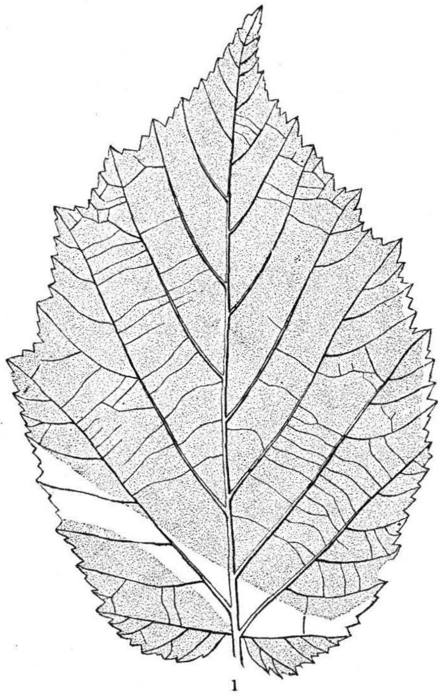
DICOTYLEDONS.

FIG. 1. Populus craspedodroma, n. sp. FIG. 2. P. Whitei, n. sp. FIG. 3. P. hederoides, n. sp. FIG. 4. P. Richardsoni, Heer. FIG. 5. P. anomala, n. sp. FIG. 6. P. Grewiopsis, n. sp. FIG. 7. P. inæqualis, n. sp. FIG. 8. Quercus bicornis, n. sp. FIGS. 9, 10. Q. Doljensis, Pilar.



DICOTYLEDONS.

FIG. 1. Quercus carbonensis, n. sp. FIG. 2. Q. Dentoni, Lx. FIGS. 3-5. Dryophyllum aquamarum, n. sp. FIGS. 6-9. D. Bruneri, n. sp. FIG. 10. D. falcatum, n. sp. FIG. 11. D. basidentatum, n. sp.



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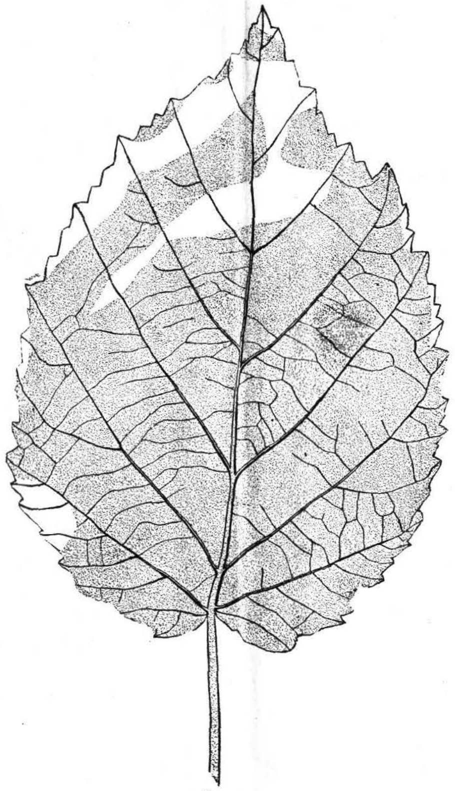

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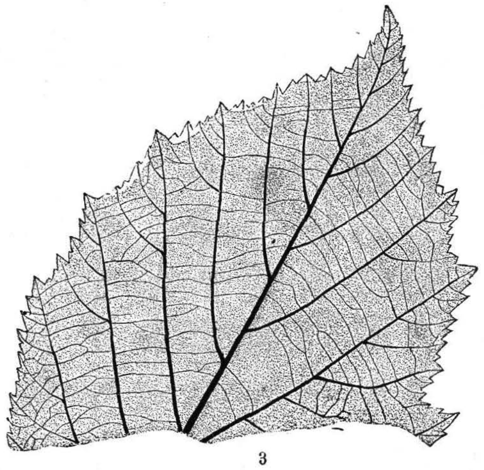

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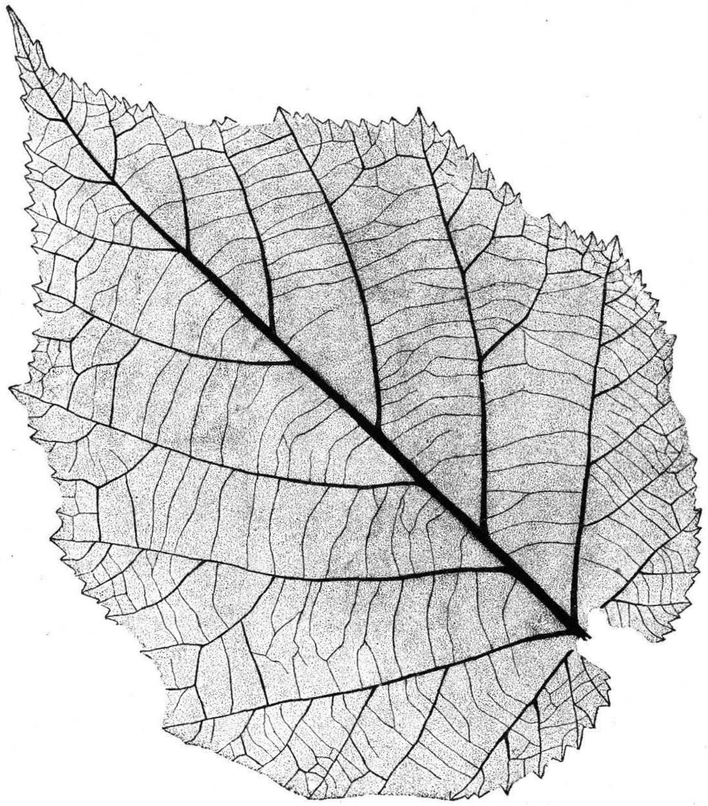

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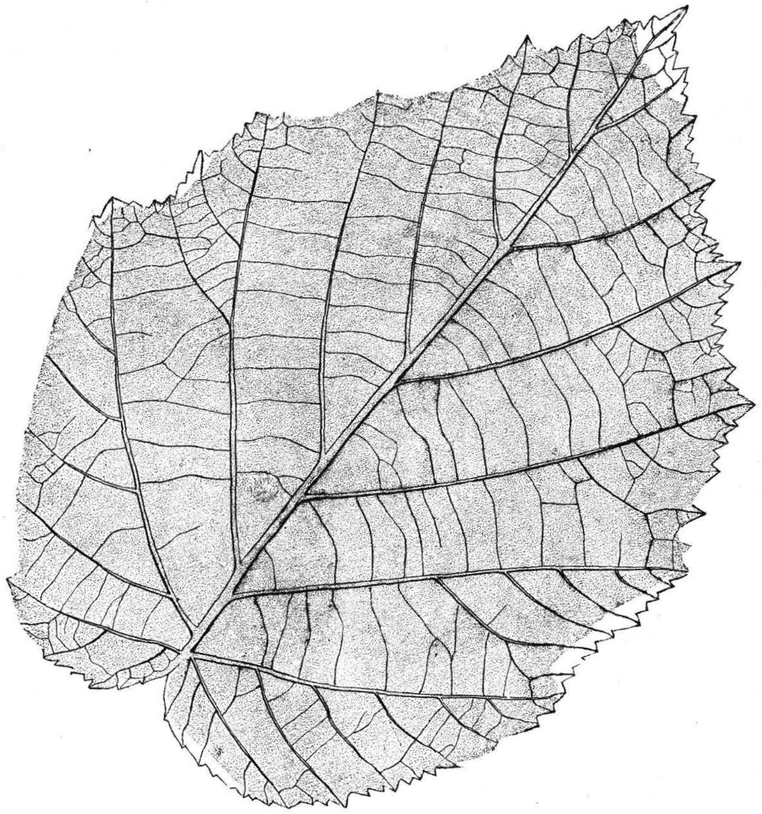

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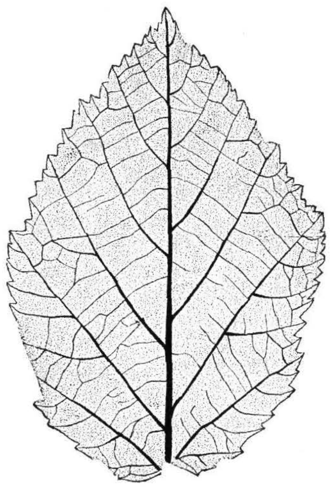
DICOTYLEDONS.

FIGS. 1–5. Corylus Americana, Walt.



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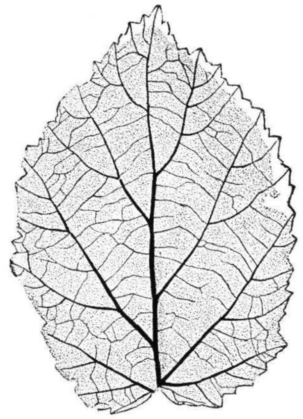

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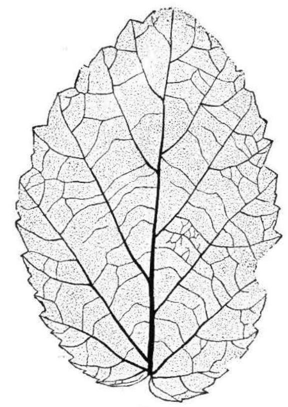

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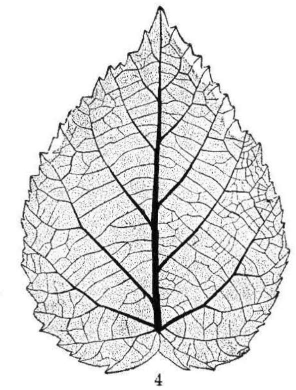

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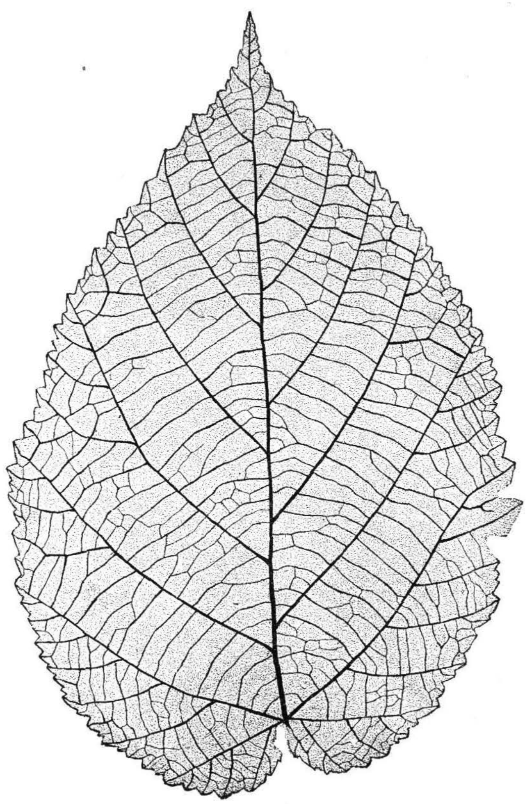

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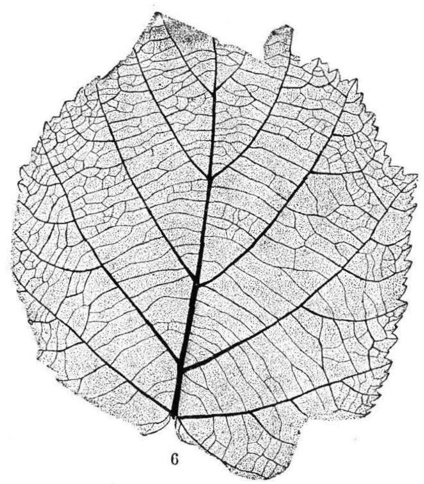

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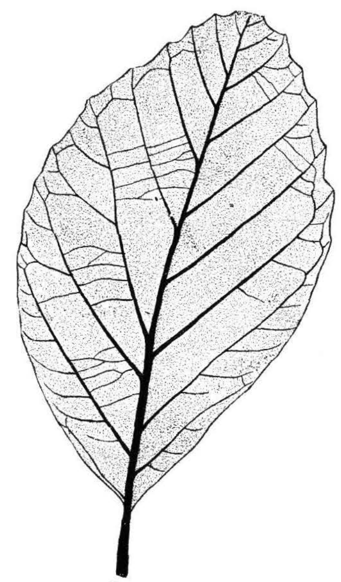

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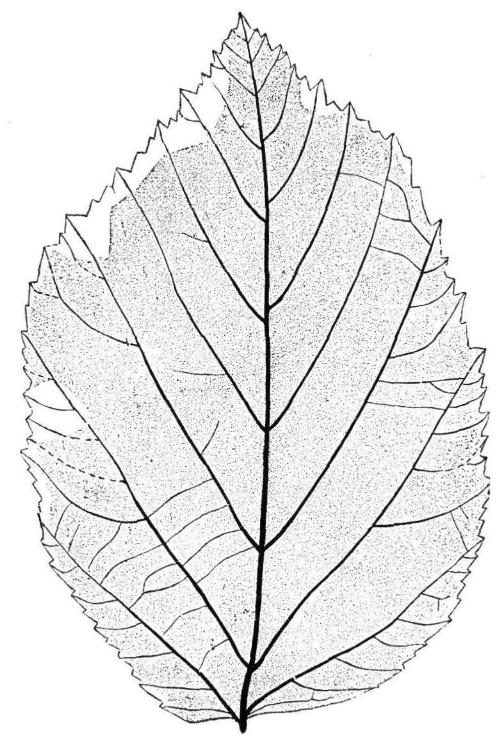

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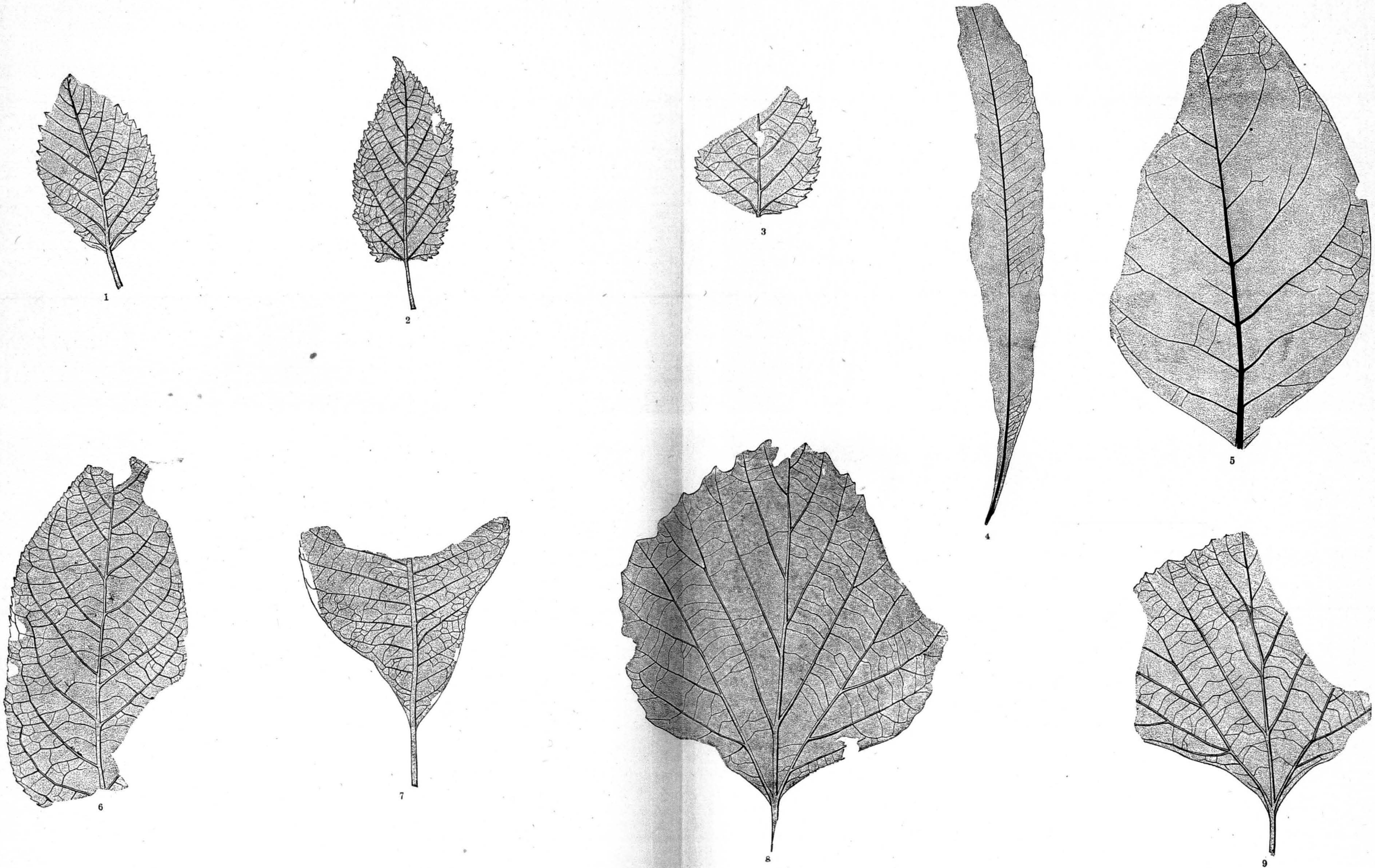
DICOTYLEDONS.

FIGS. 1–4. Corylus rostrata, Ait. FIGS. 5, 6. C. Fosteri, n. sp. FIGS. 7. ?C. McQuarrii, Heer. FIG. 8. Alnus Grewiopsis, n. sp.



DICOTYLEDONS.

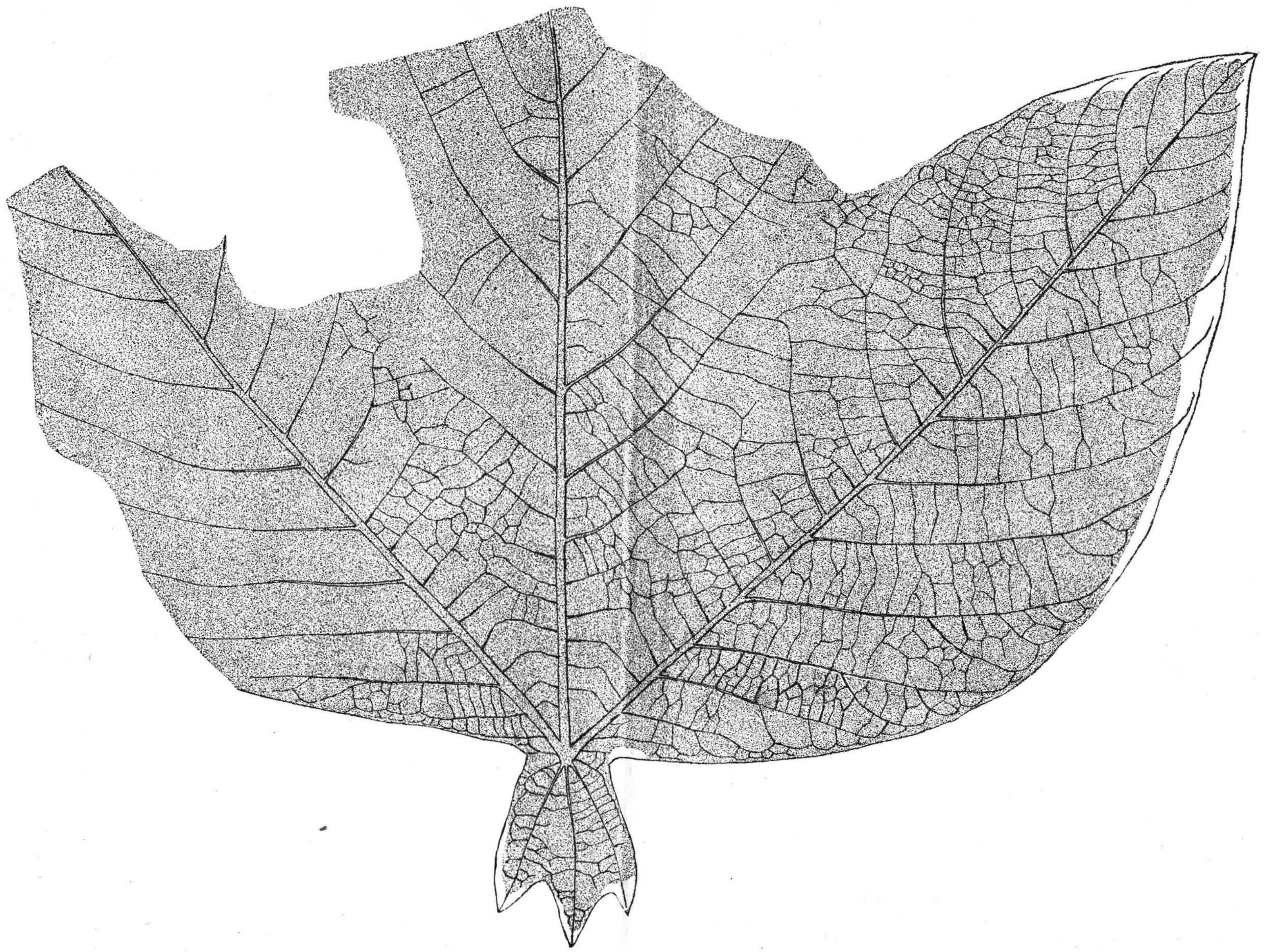
FIG. 1. Betula prisca, Ett. FIG. 2. B. coryloides, n. sp. FIG. 3. B. basiserrata, n. sp FIG. 4. Myrica Torreyi, Lx. FIG. 5. ?Juglans Ungeri, Heer. FIG. 6. J. nigella, Ung. FIG. 7. Carya antiquorum, Lx. FIGS. 8, 9. Platanus Heerii, Lx.

DICOTYLEDONS.

FIG. 1. Platanus nobilis, Newby.

DICOTYLEDONS.

FIGS. 1-4. Platanus basilobata, n. sp. FIG. 4*a*. Enlarged detail.



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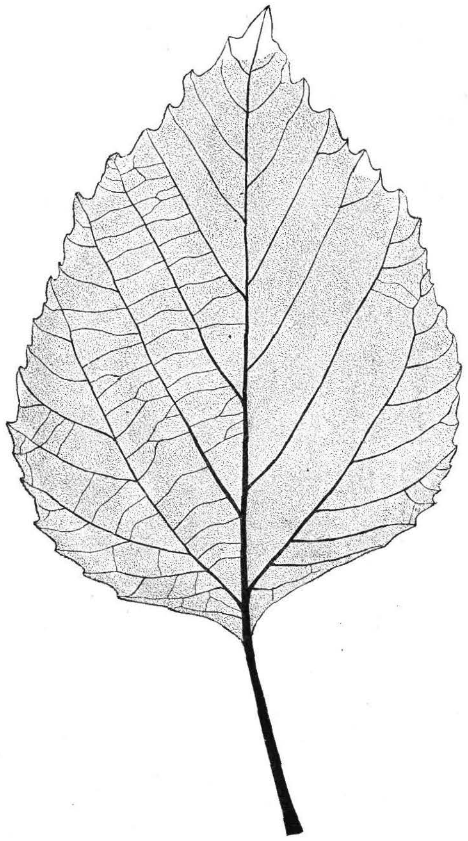
DICOTYLEDONS.

FIG. 1. Platanus basilobata, n. sp.



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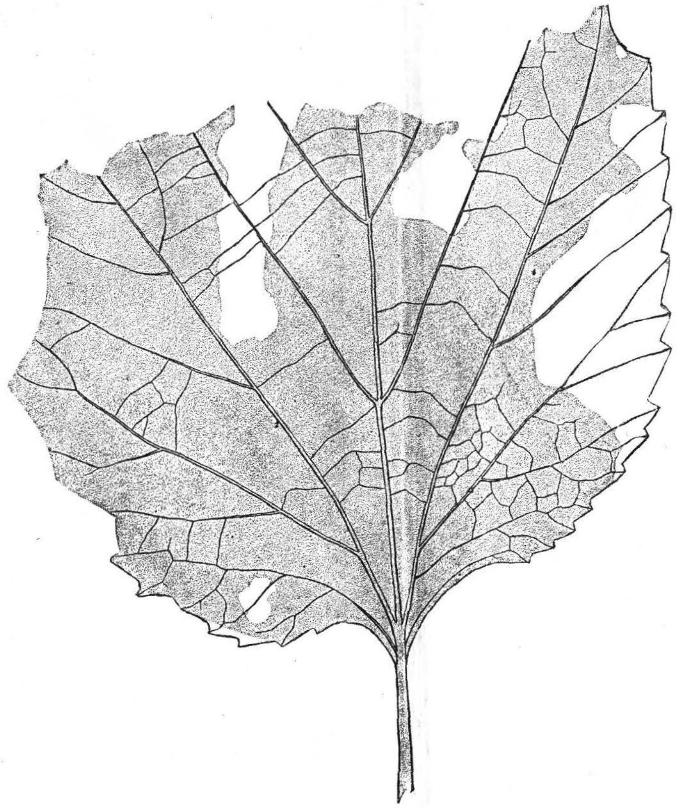

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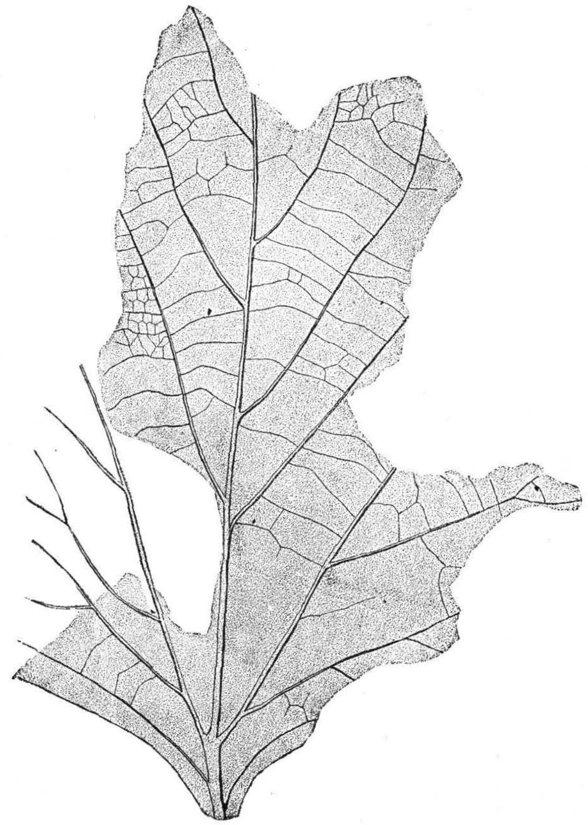

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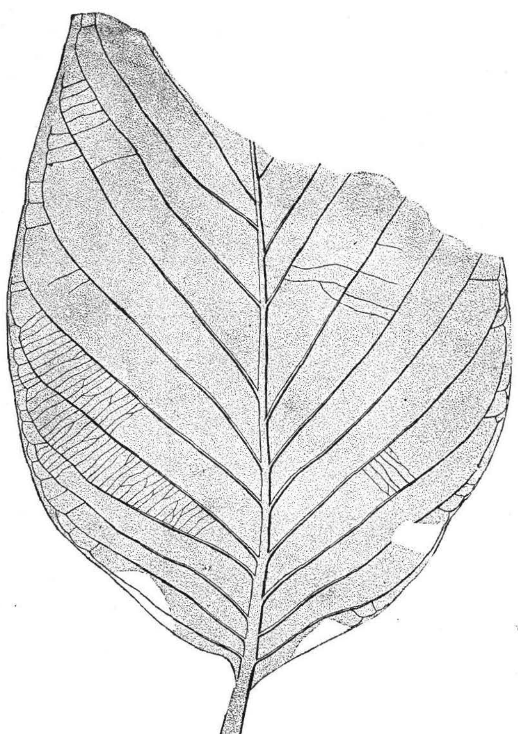

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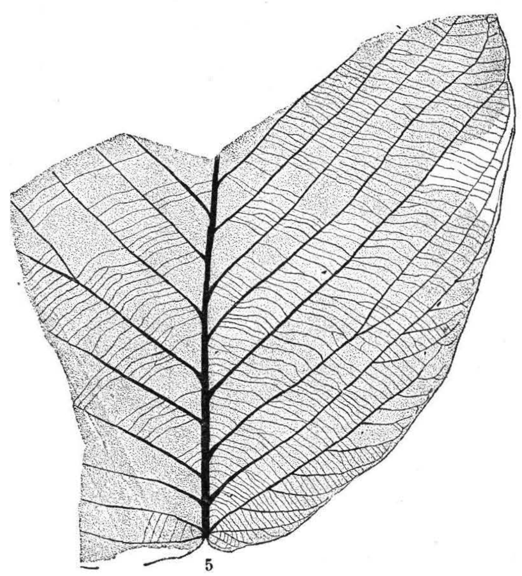

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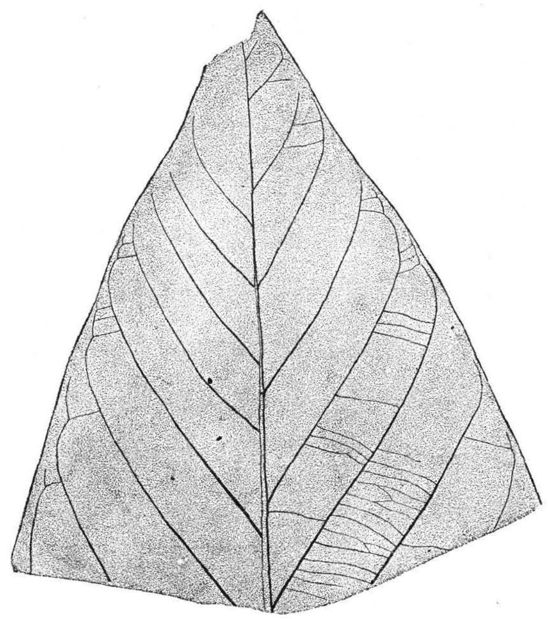

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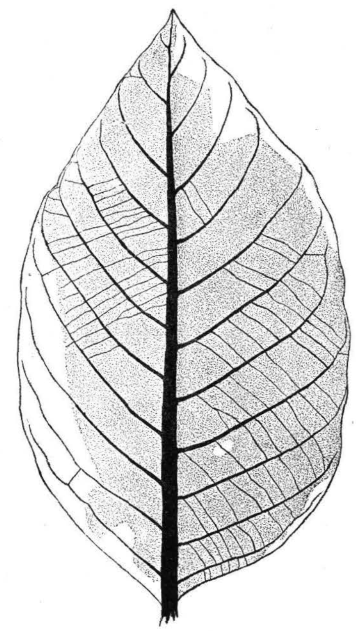

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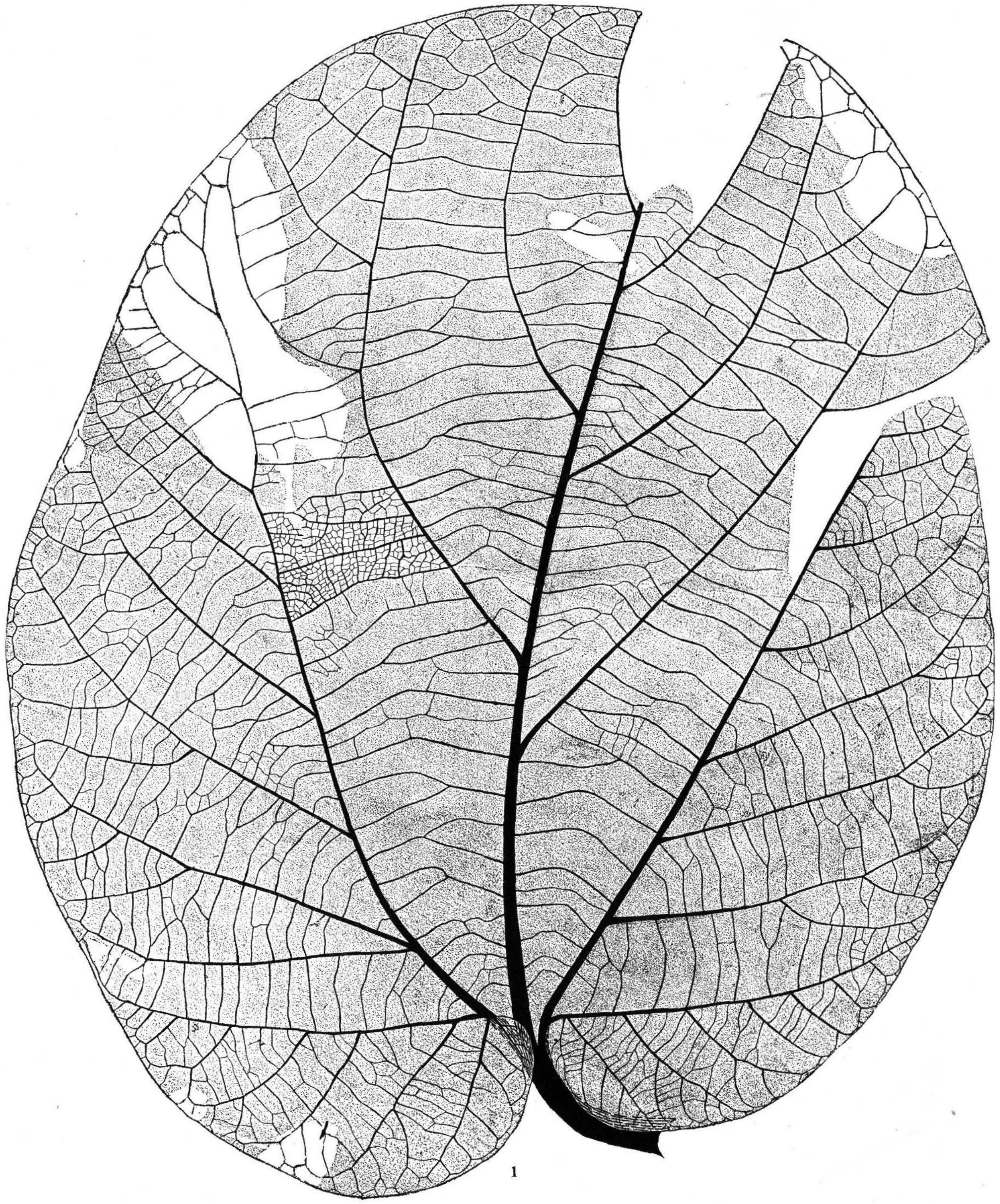
DICOTYLEDONS.

FIG. 1. Platanus Guillelmæ, Göpp. FIGS. 2, 3. P. Raynoldsii, Newby. FIGS. 4, 5. Ficus irregularis, Lx. FIG. 6. F. spectabilis, Lx. FIG. 7 F. Crossii, n. sp.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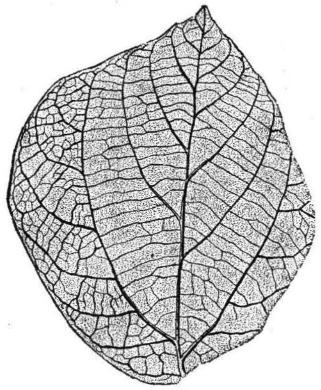
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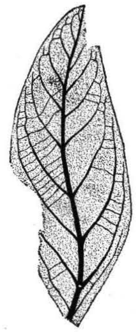
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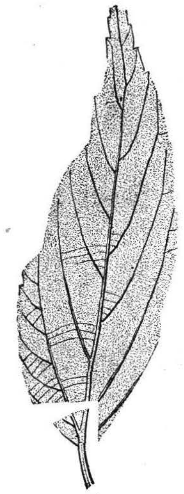
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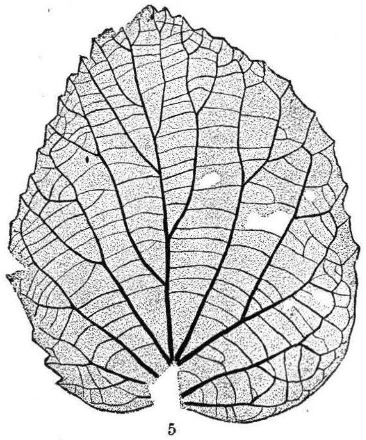
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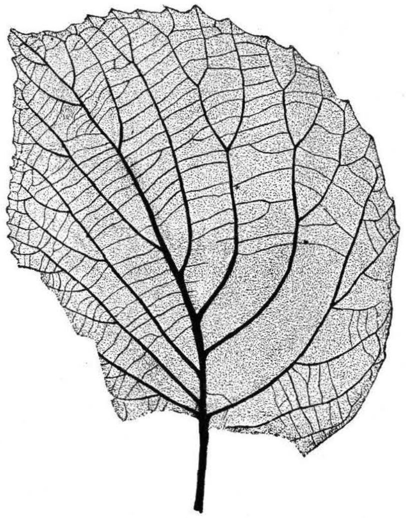
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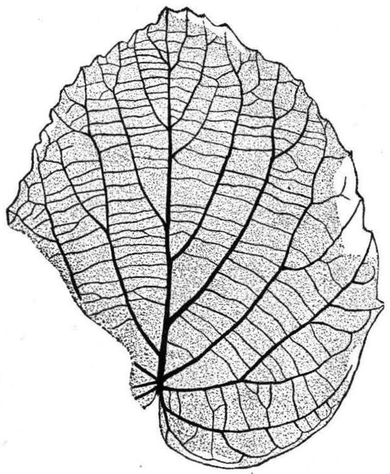
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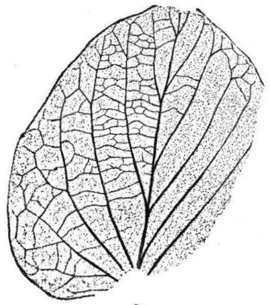
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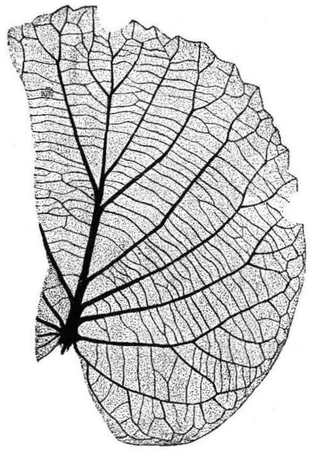
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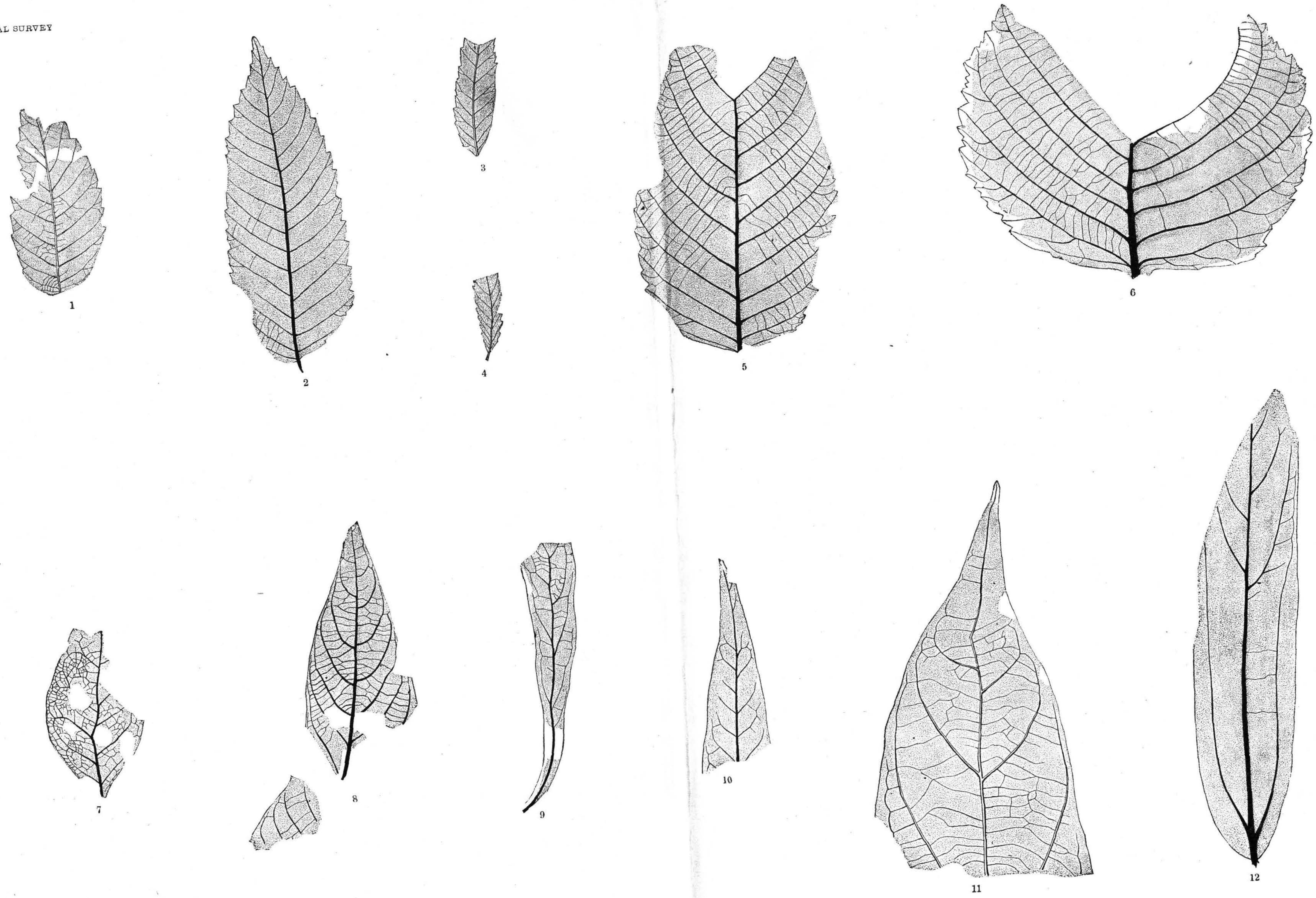
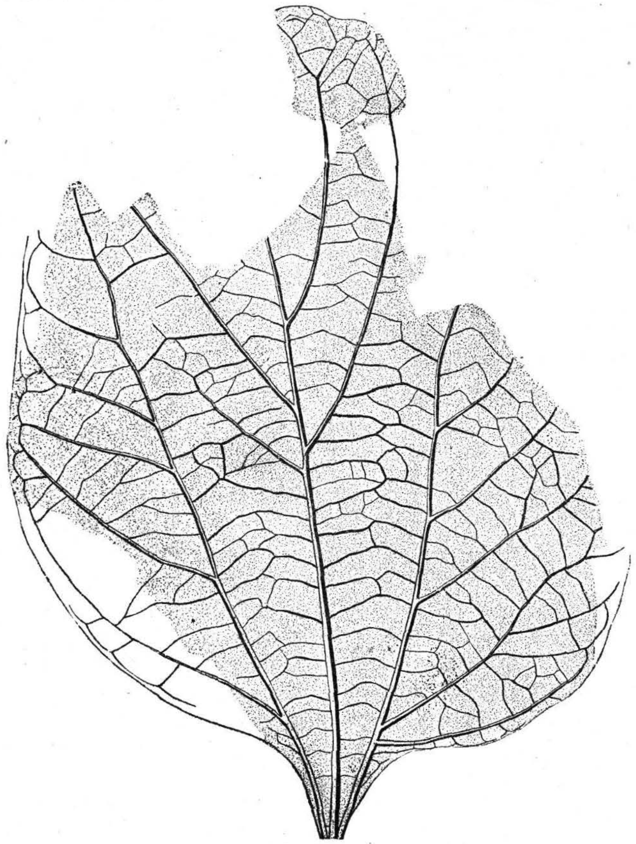
DICOTYLEDONS.

FIG. 1. Ficus speciosissima, n. sp. FIG. 2. F tiliæfolia, Heer. FIG. 3. F. sinuosa, n. sp. FIG. 4. F. limpida, n. sp. FIGS. 5-9. F. viburnifolia, n. sp.



DICOTYLEDONS.

FIGS. 1, 2. Ulmus planeroides, n. sp. FIGS. 3, 4. U. minima, n. sp. FIG. 5. U. rhamnifolia, n. sp. FIG. 6. U. orbicularis, n. sp. FIG. 7. Laurus resurgens, Sap. FIGS. 8–10. L. primigenia, Ung. FIG. 11. Litsæa Carbonensis, n. sp. FIG. 12. Cinnamomum lanceolatum, Heer.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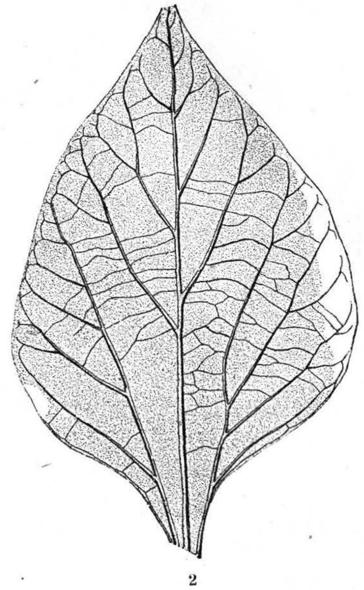
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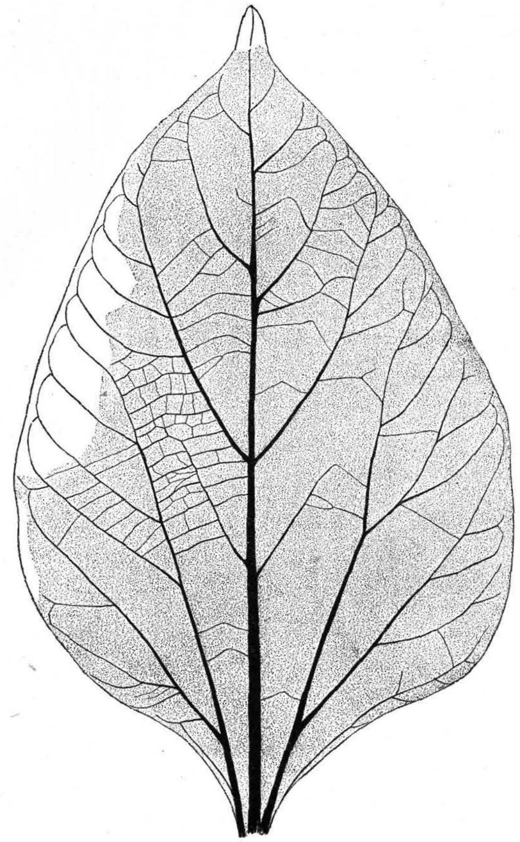
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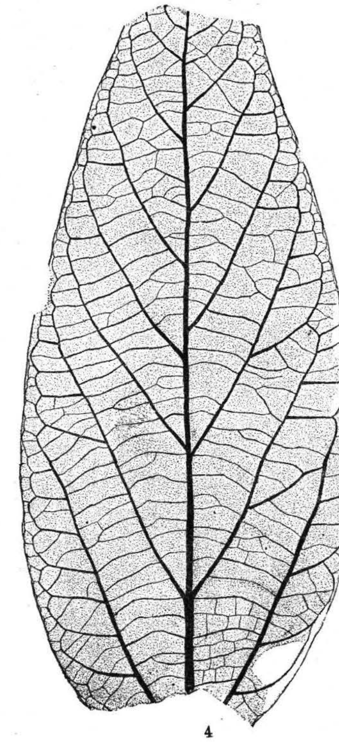
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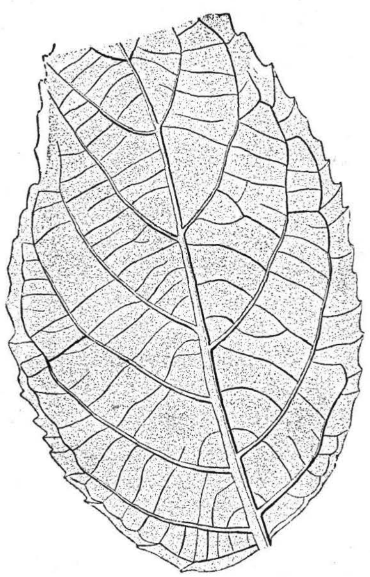
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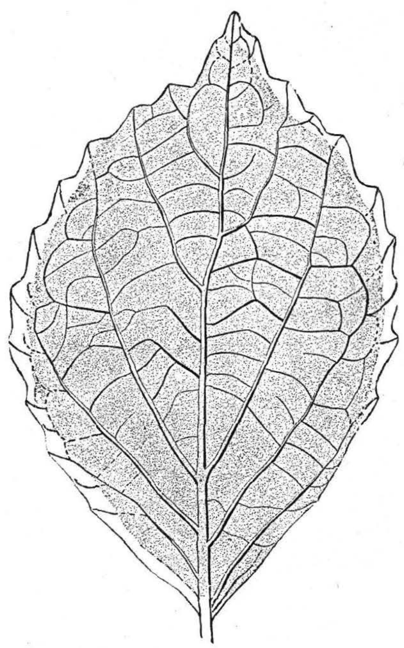
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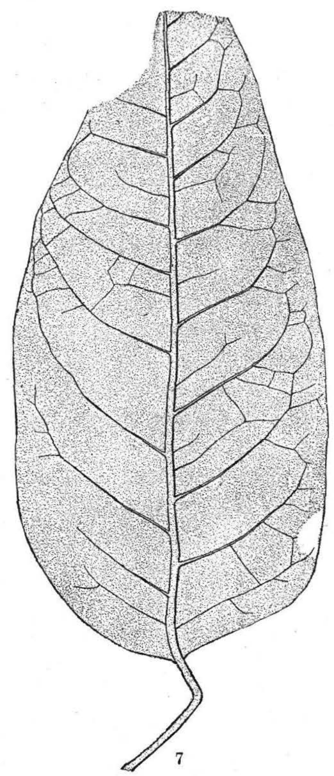
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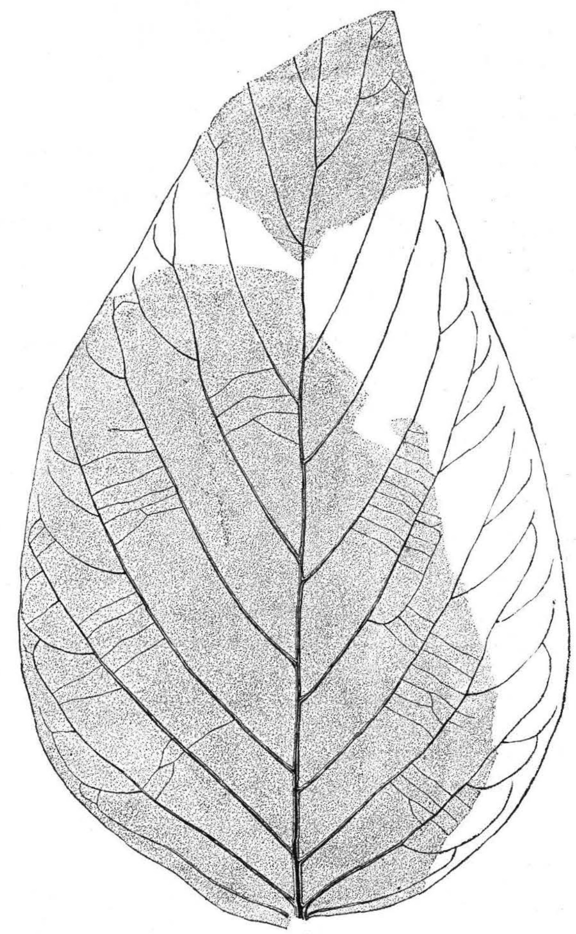
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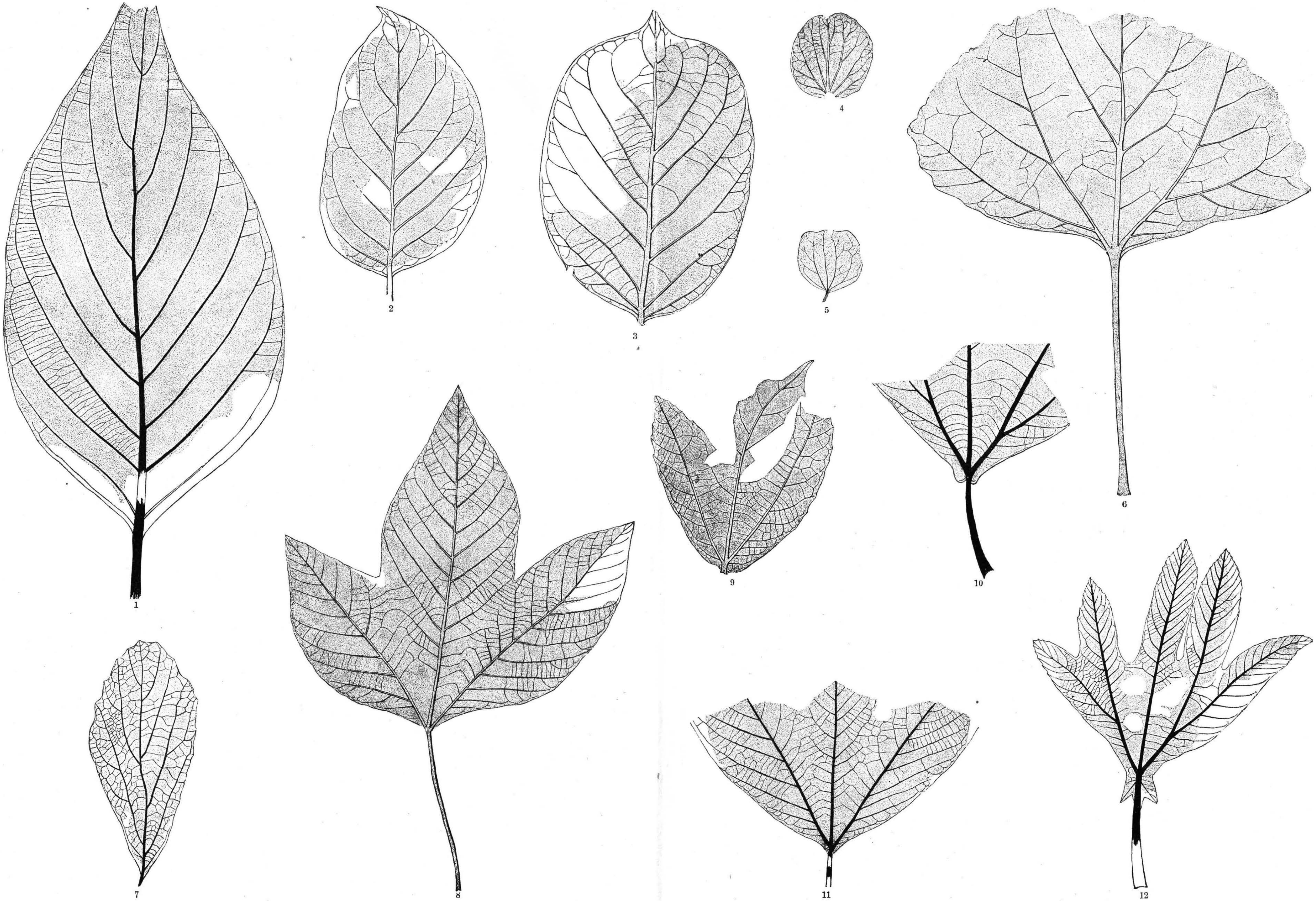
DICOTYLEDONS.

FIGS. 1–3. Cinnamomum affine, Lx. FIG. 4. Daphnogene elegans, Wat. FIG. 5. ? Monimiopsis amboræfolia, Sap. FIG. 6. ? M. fraterna, Sap. FIG. 7 Nyssa Buddiana, n. sp. FIG. 8. Cornus Fosteri, n. sp.



DICOTYLEDONS.

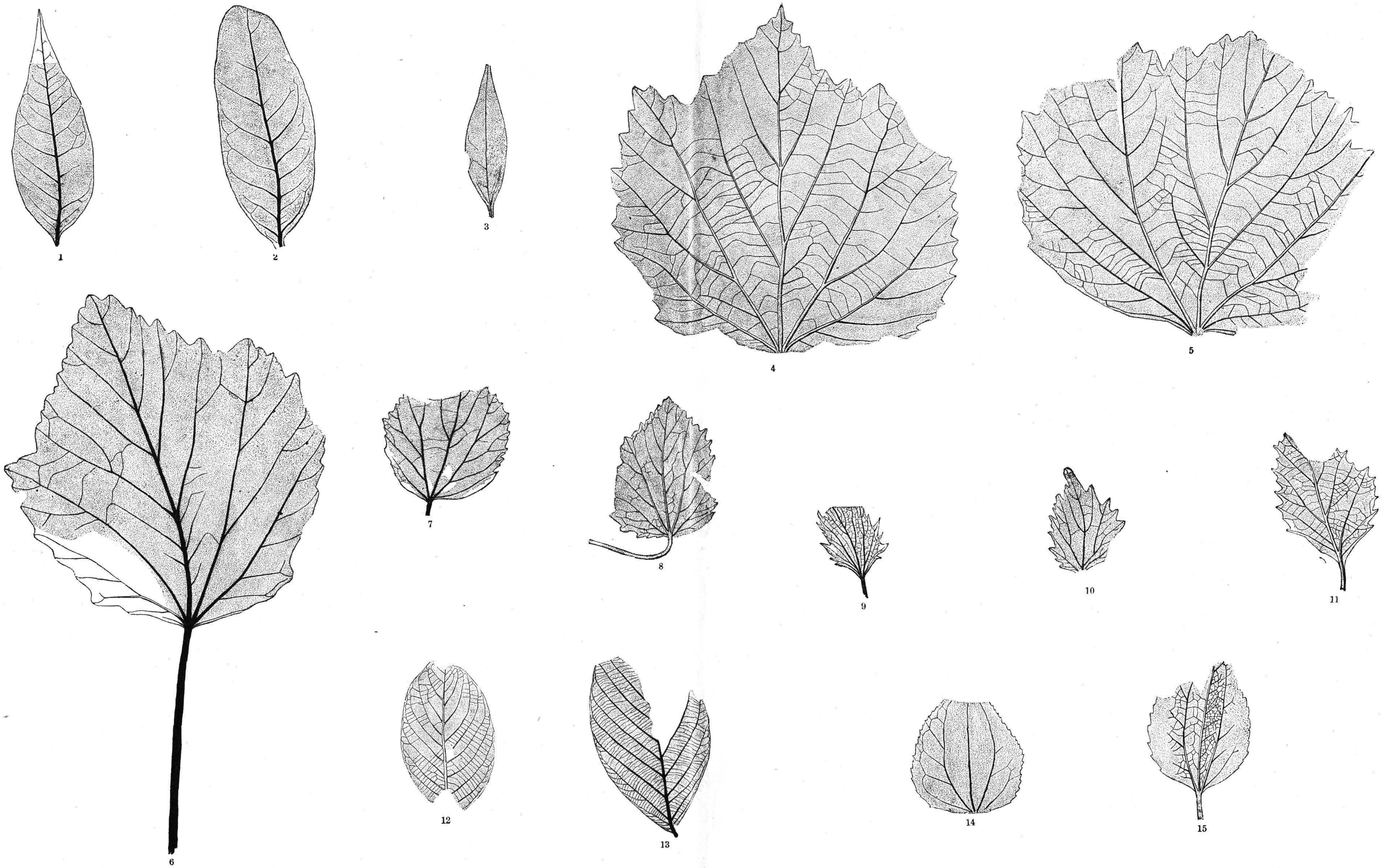
FIG. 1. Cornus Studeri, Heer. FIGS. 2, 3. C. Emmonsii, n. sp. FIG. 4. Hedera parvula, n. sp. FIG. 5. H. minima, n. sp. FIG. 6. H. Bruneri, n. sp. FIG. 7. H. aquamara, n. sp. FIG. 8. Aralia notata, Lx. FIG. 9. A. Looziana, Sap. & Mar. FIGS. 10–12. A. digitata, n. sp.

DICOTYLEDONS.

FIG. 1. Aralia digitata, n. sp. FIGS. 2–5. Trapa microphylla, Lx. FIG. 6. Hamamelites fothergilloides, Sap. FIG. 7. Leguminosites arachioides, Lx. FIGS. 8, 9. Acer trilobatum tricuspidatum, Heer.

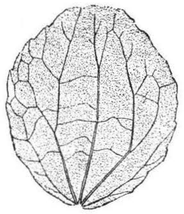
DICOTYLEDONS.

FIG. 1. Acer indivisum, Web. FIGS. 2, 3. Sapindus affinis, Newby. FIGS. 4-8. S. grandifolius, n. sp. FIGS. 9, 10. S. alatus, n. sp.



DICOTYLEDONS.

FIGS. 1-3. Sapindus angustifolius, Lx. FIGS. 4, 5. Vitis Bruneri, n. sp. FIG. 6. V. Carbonensis, n. sp. FIGS. 7, 8. V. Xantholithensis, n. sp. FIGS. 9-11. V. cuspidata, n. sp. FIGS. 12, 13. Berchemia multinervis, Al. Br. FIGS. 14, 15. Zizyphus serrulata, n. sp.



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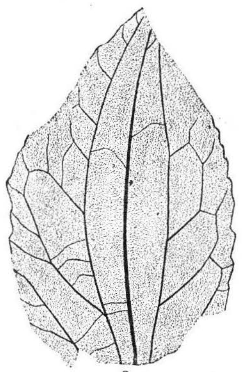

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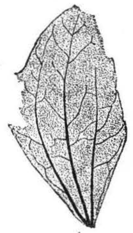

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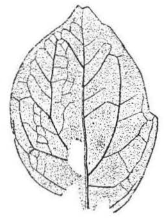

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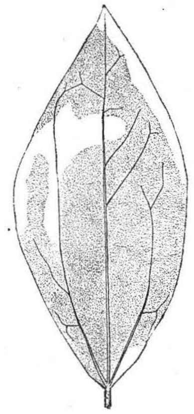

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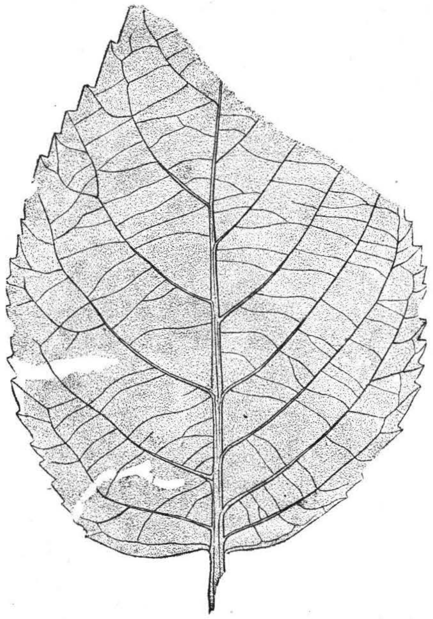

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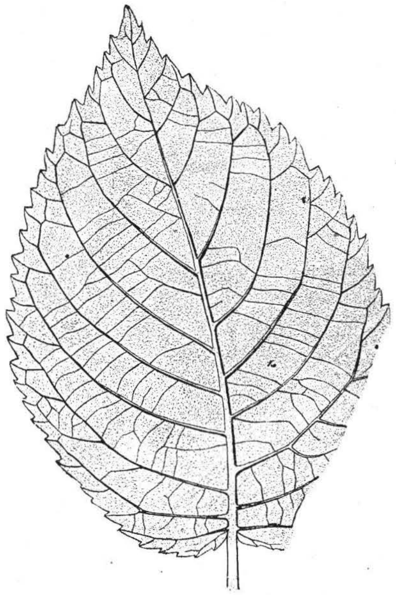

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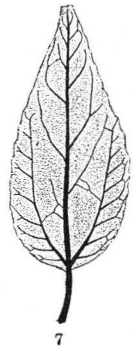

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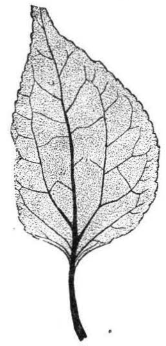

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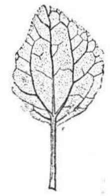

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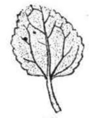

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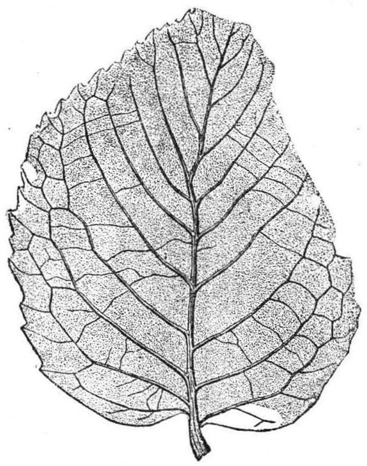

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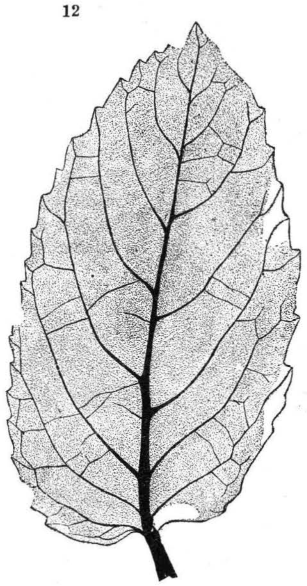

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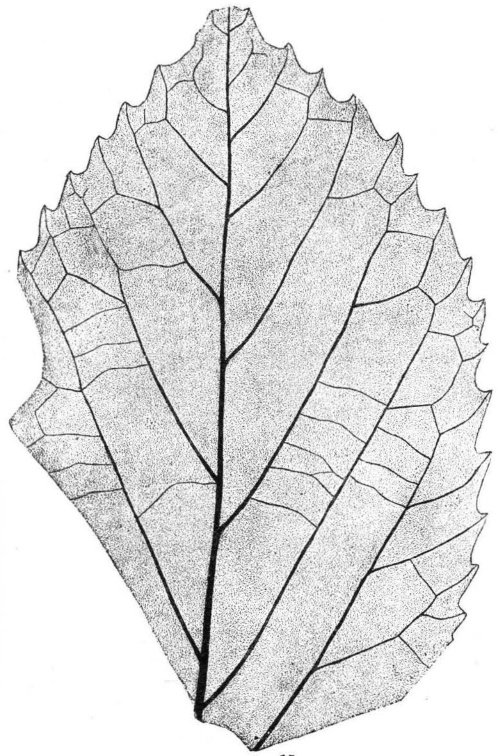

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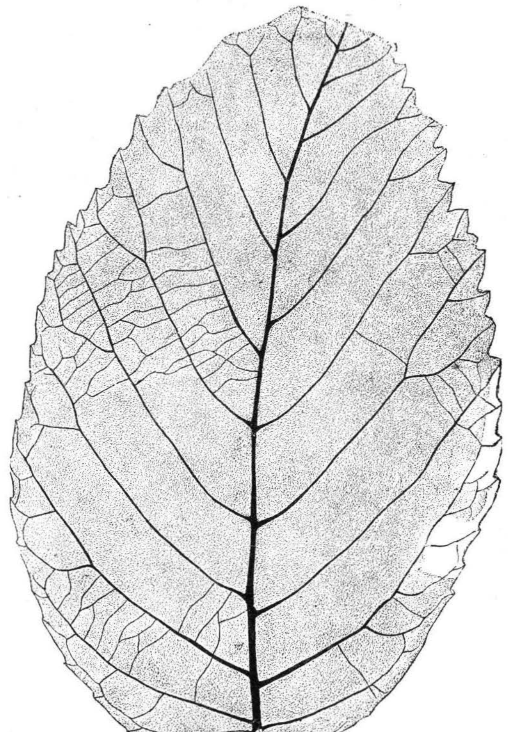
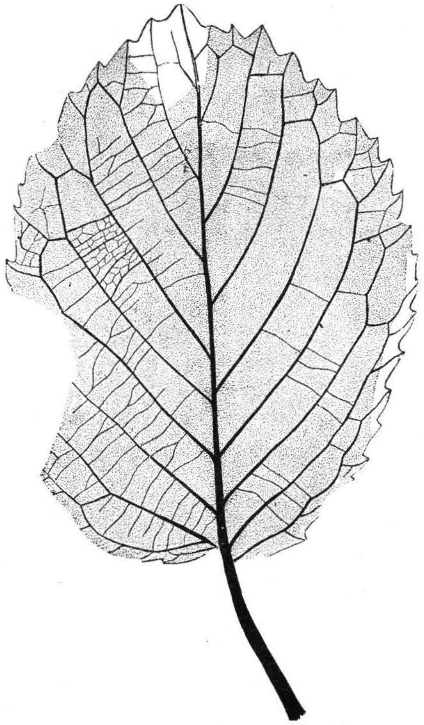


16

DICOTYLEDONS.

FIGS. 1, 2. Zizyphus Meekii, Lx. FIG. 3. Z. cinnamomoides, Lx. FIGS. 4–6. Paliurus Colombi, Heer. FIG. 7. P. pulcherrima, n. sp. FIGS. 8–10. P. Pealei, n. sp. FIGS. 11–14. Celastrus ferrugineus, n. sp. FIGS. 15, 16. C. Taurinensis, n. sp.



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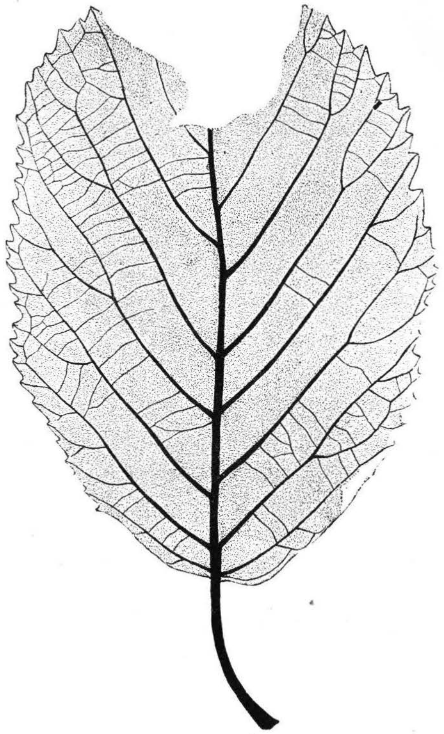

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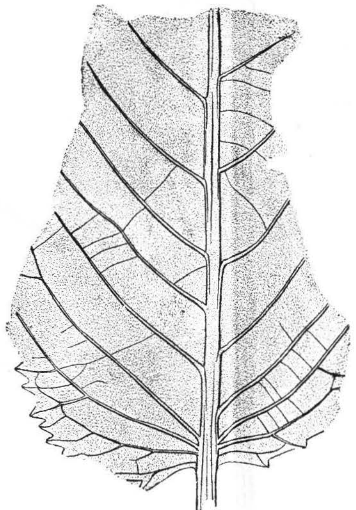

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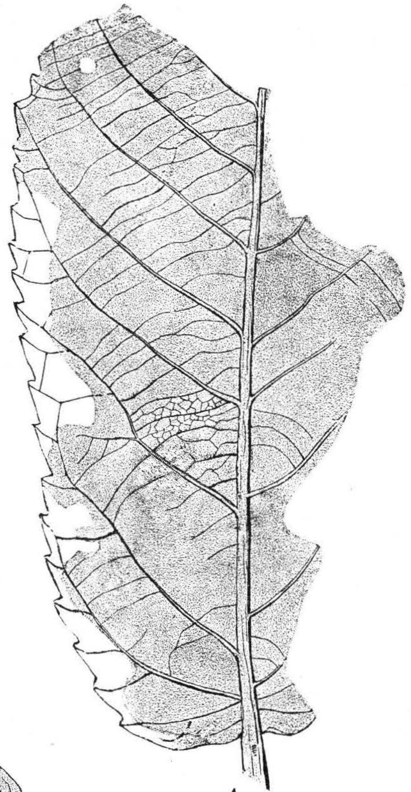

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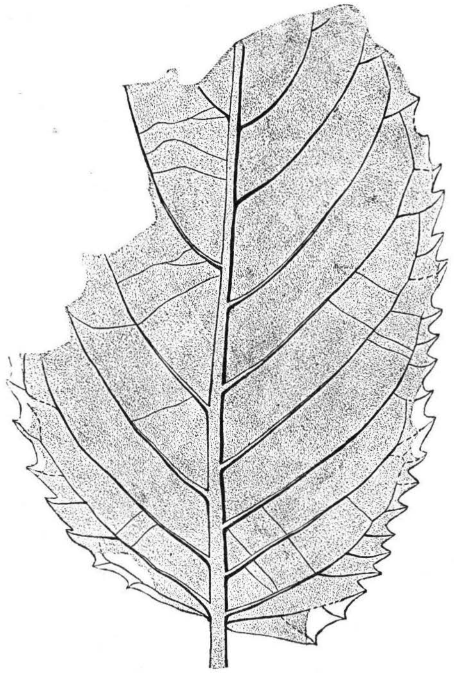

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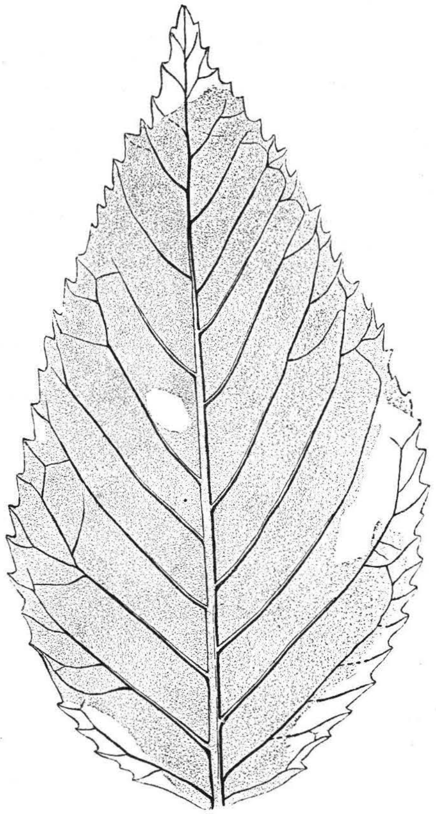

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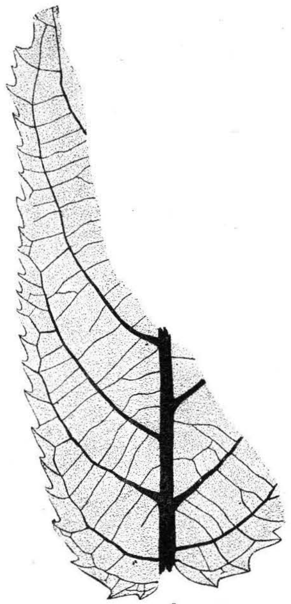

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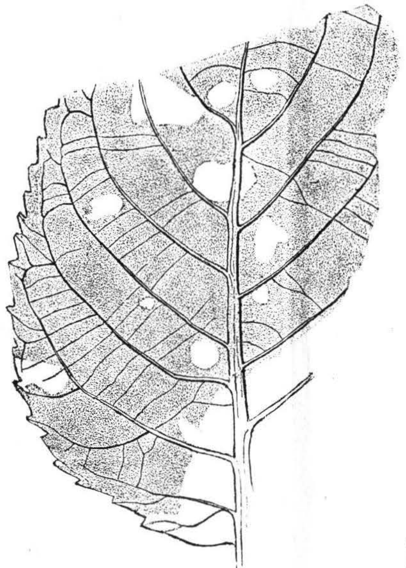

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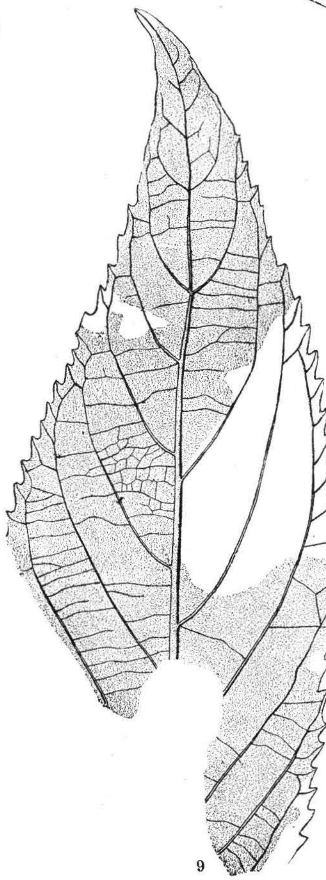

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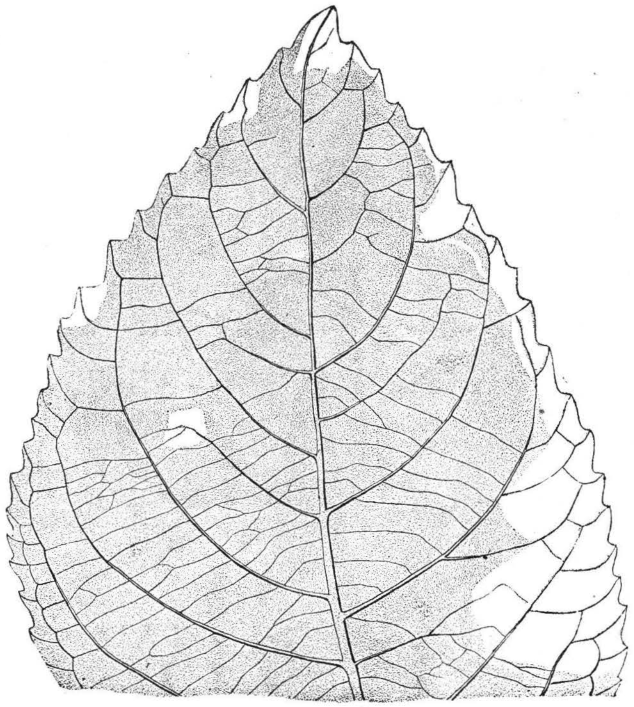

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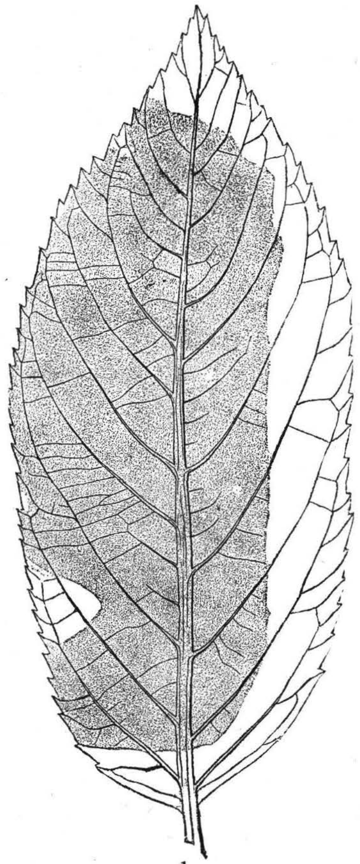
DICOTYLEDONS.

FIGS. 1, 2. Celastrus alnifolius, n. sp. FIGS. 3–6. C. pterospermoides, n. sp. FIG. 7. C. ovatus, n. sp. FIG. 8. C. grewiopsis, n. sp. FIGS. 9, 10. C. curvinervis, n. sp.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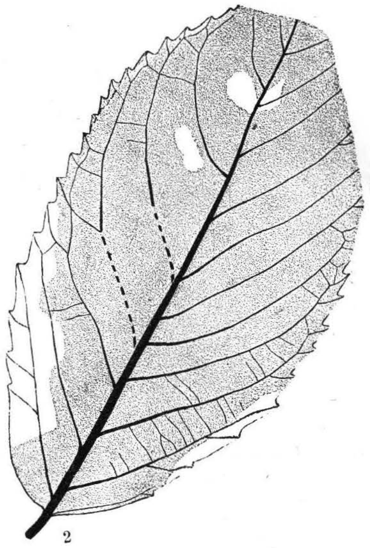
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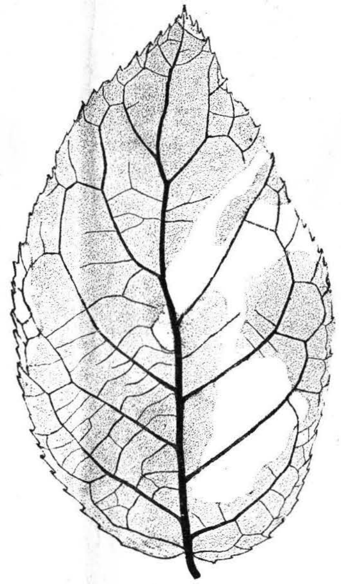
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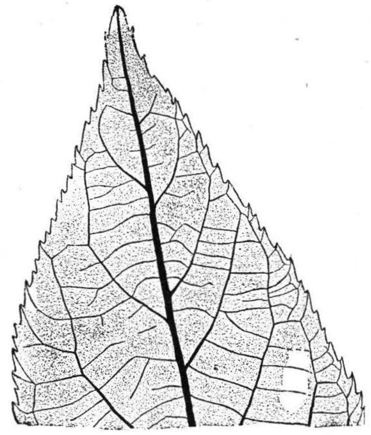
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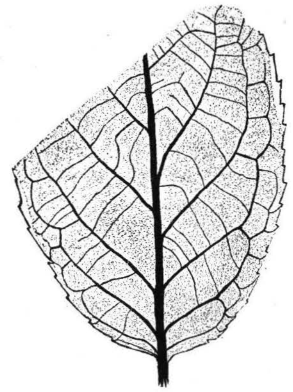
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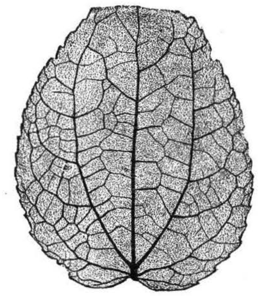
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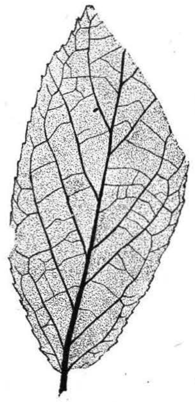
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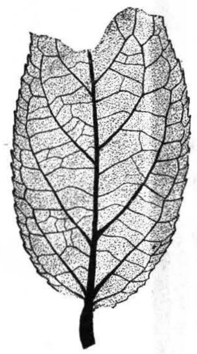
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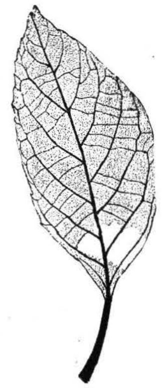
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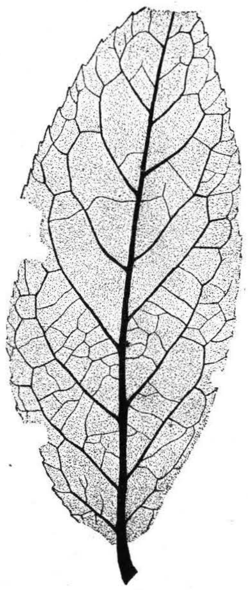
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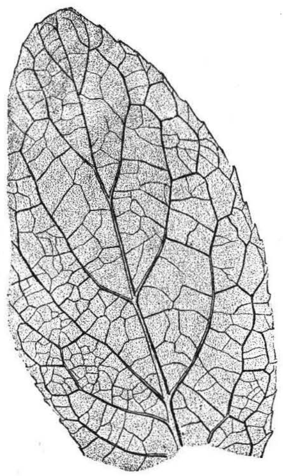
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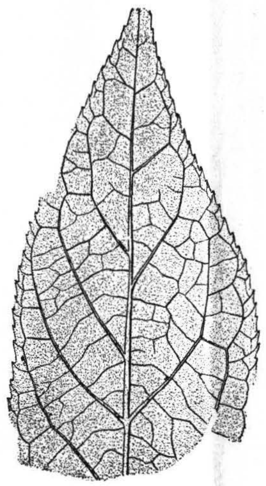
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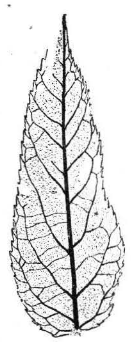
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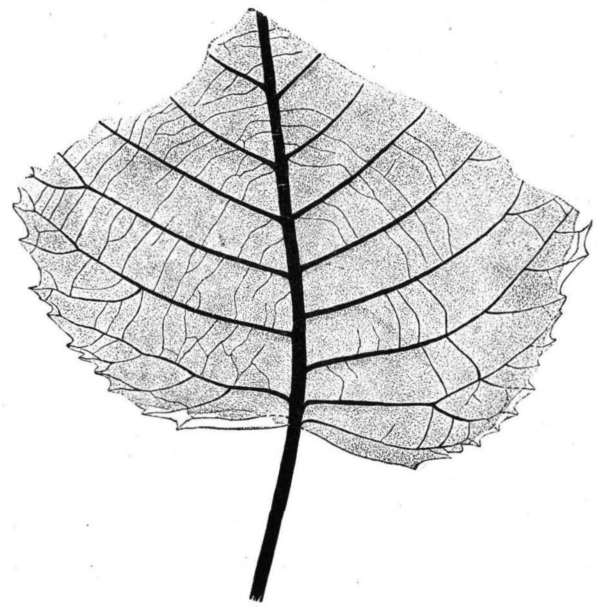
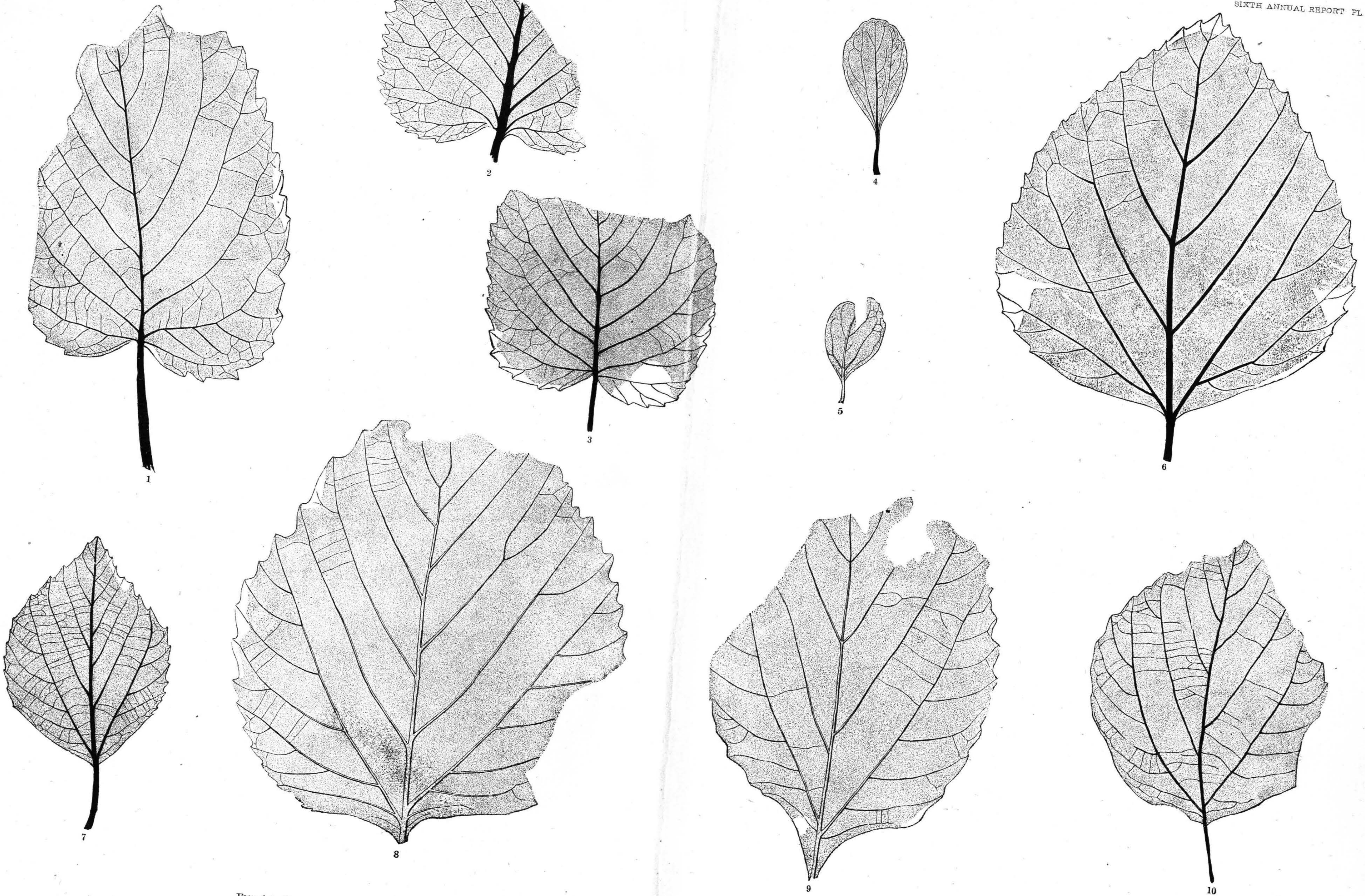

14

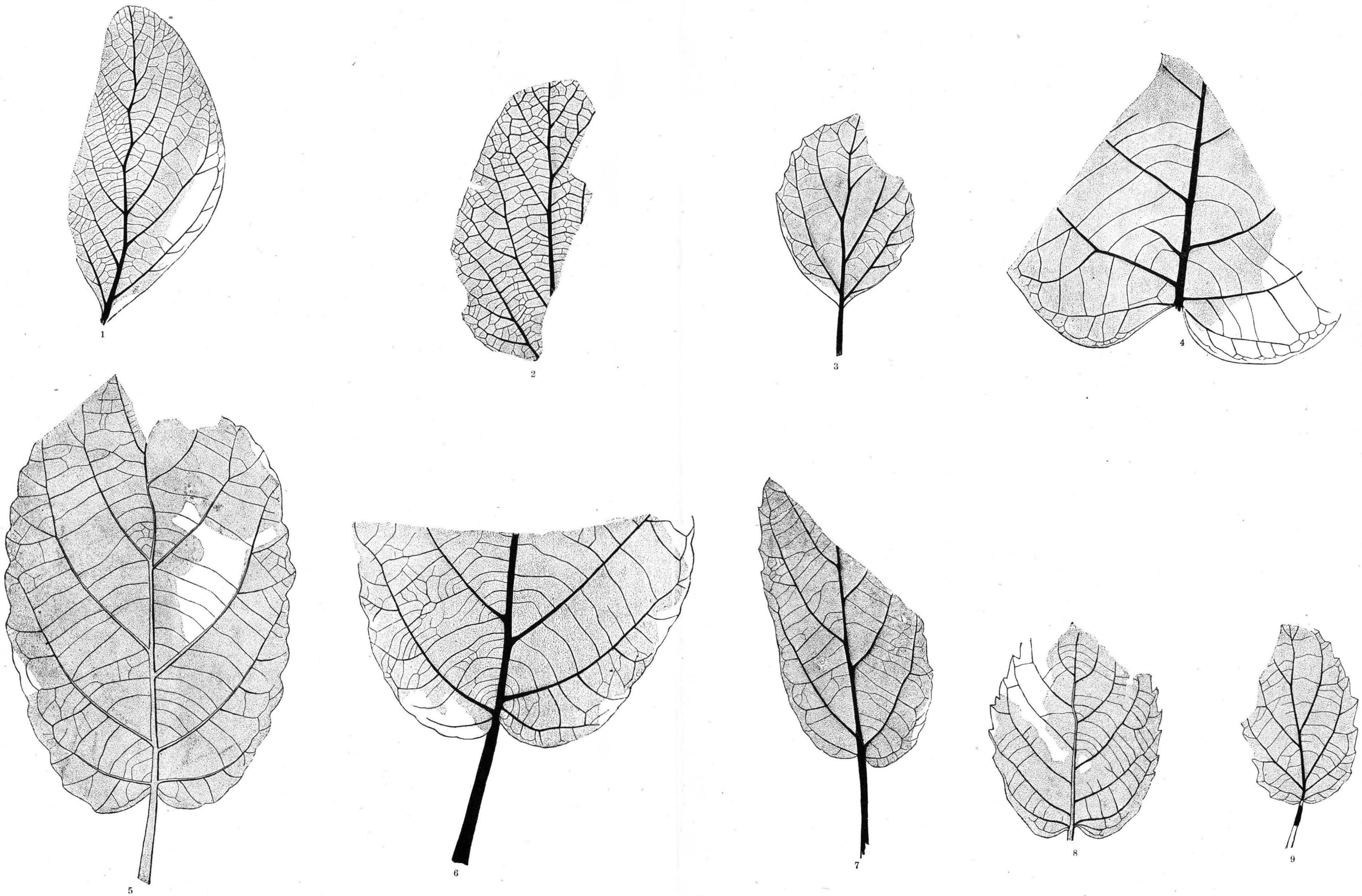
DICOTYLEDONS.

FIGS. 1, 2. Euonymus Xantholithensis, n. sp. FIGS. 3–5. Elæodendron serrulatum, n. sp. FIGS. 6–12. E polymorphum, n. sp. FIG. 13. Grewia crenata (Ung.), Heer. FIG. 14. G. celastroides, n. sp.



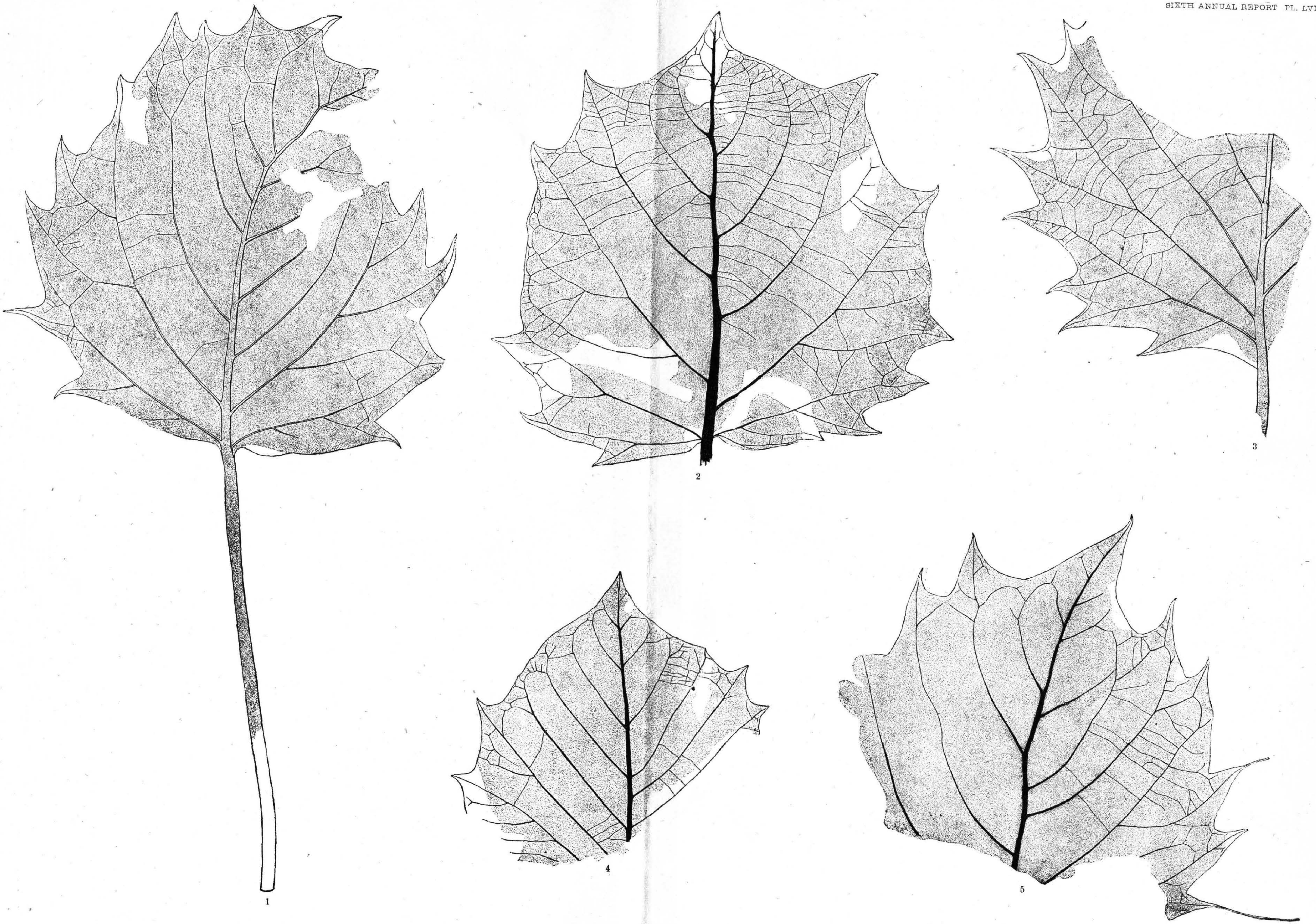
DICOTYLEDONS.

FIGS. 1-3. Grewia Pealei, n. sp. FIGS. 4, 5. G. obovata, Heer. FIG. 6. Grewiopsis platanifolia, n. sp. FIG. 7. G. viburnifolia, n. sp. FIGS. 8-10. G. populifolia, n. sp.



DICOTYLEDONS.

FIGS. 1, 2. *Grewiopsis ficifolia*, n. sp. FIG. 3. *G. paliurifolia*, n. sp. FIG. 4 *Pterospermites cordatus*, n. sp. FIGS 5, 6. *P. Whitei*, n. sp. FIGS. 7–9. *P. minor*, n. sp.

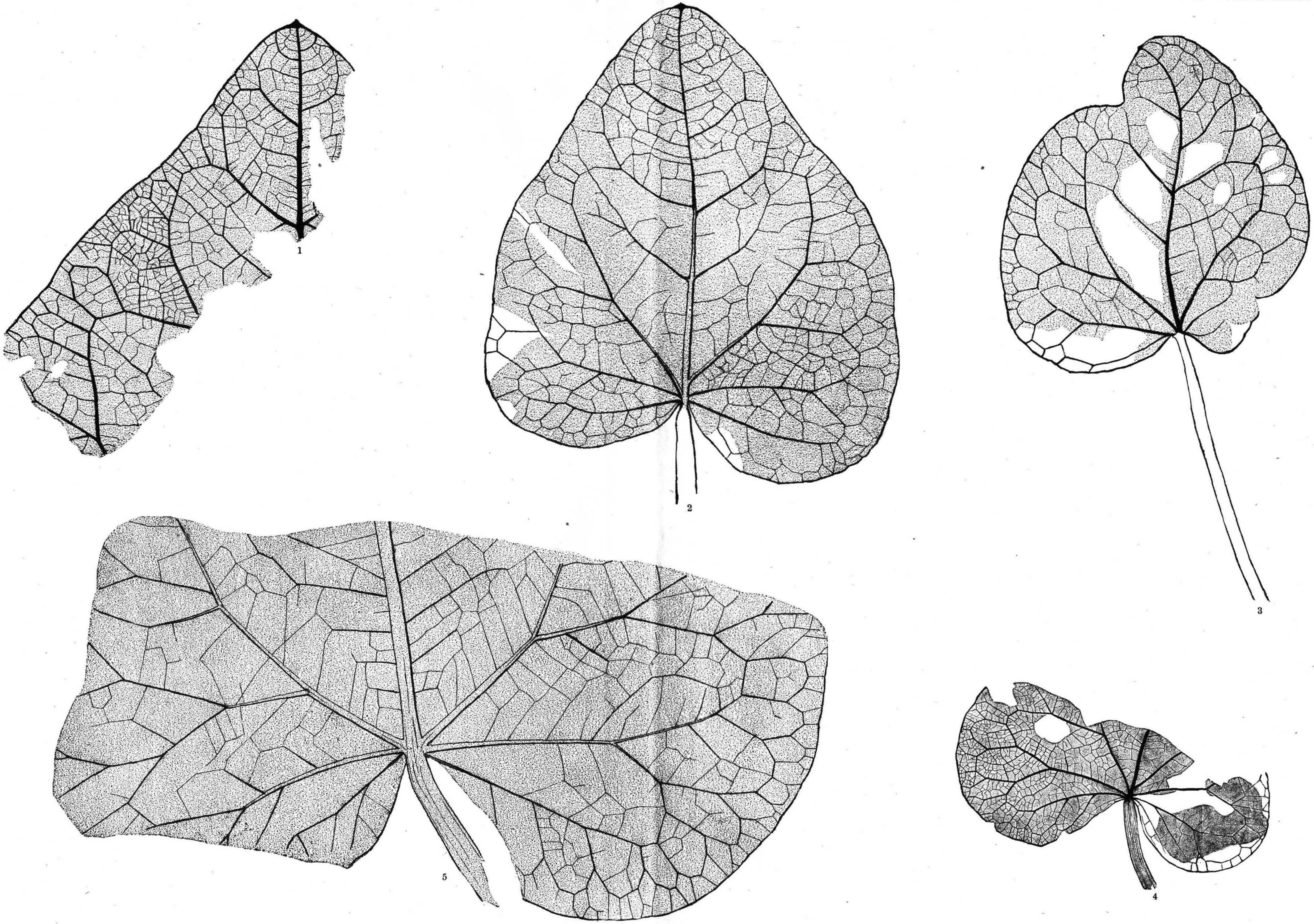


DICOTYLEDONS.

FIGS. 1–5. Credneria? daturæfolia, n. sp.

DICOTYLEDONS.

FIGS. 1-5. Credneria? daturæfolia, n. sp. FIG. 6. Datura Stramonium, L.



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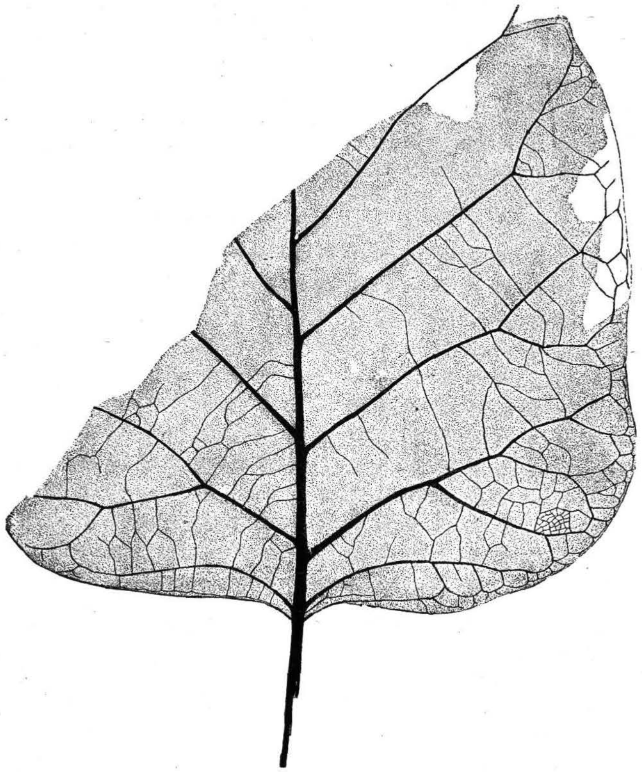
FIGS. 1-5. Cocculus Haydenianus, n. sp.



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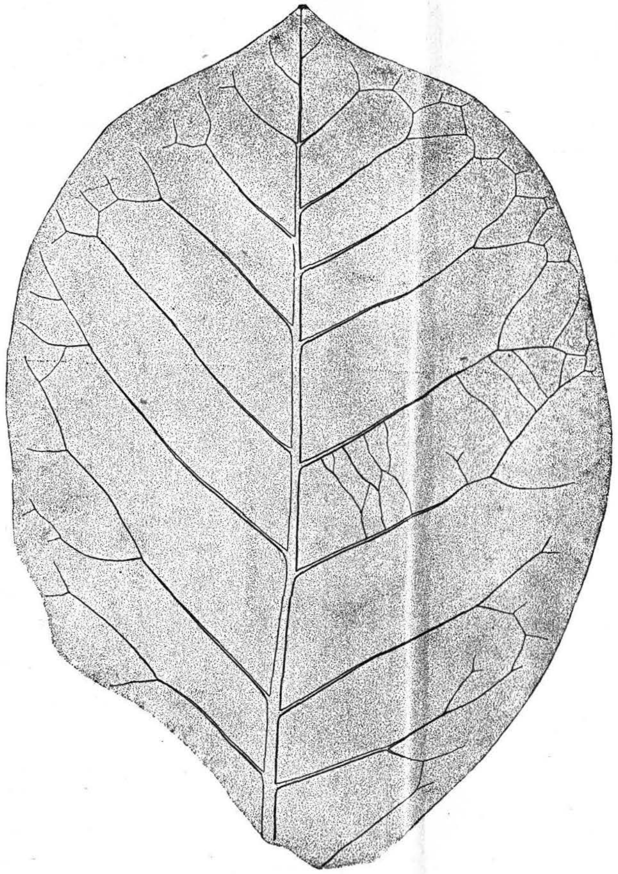

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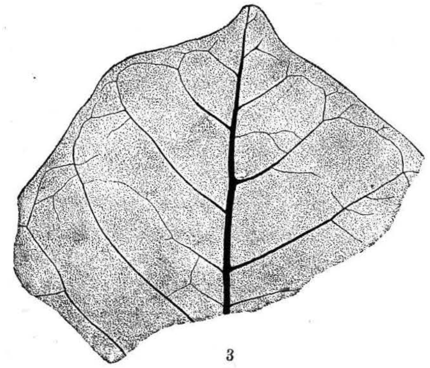

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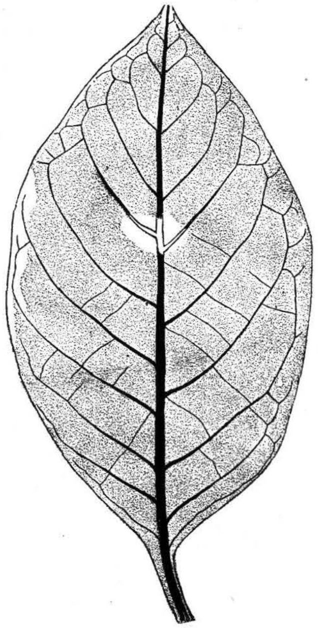

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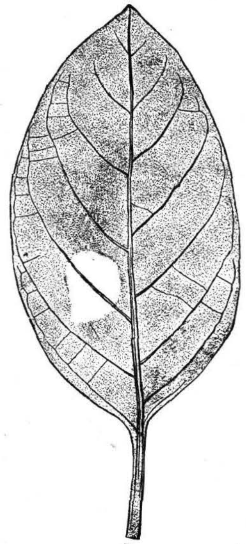

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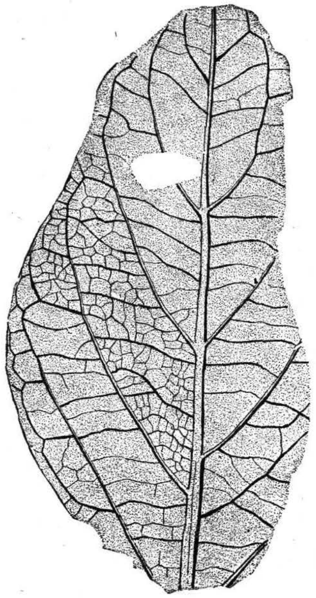

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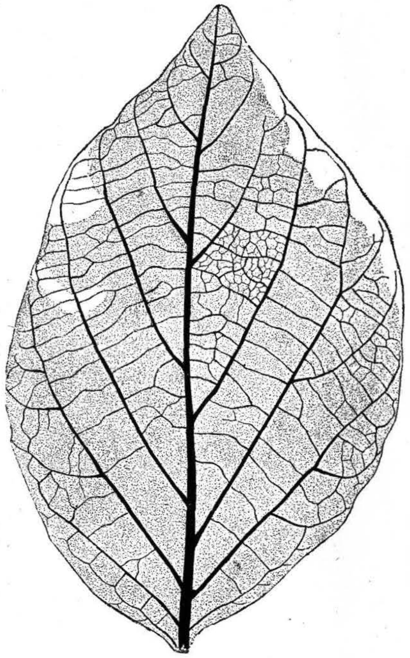

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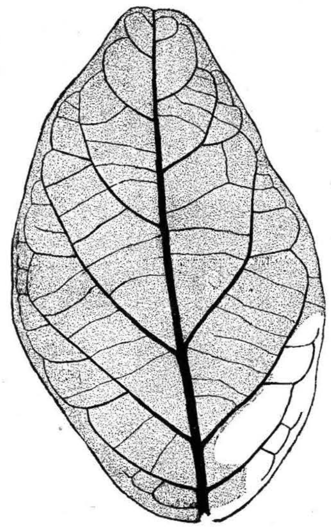

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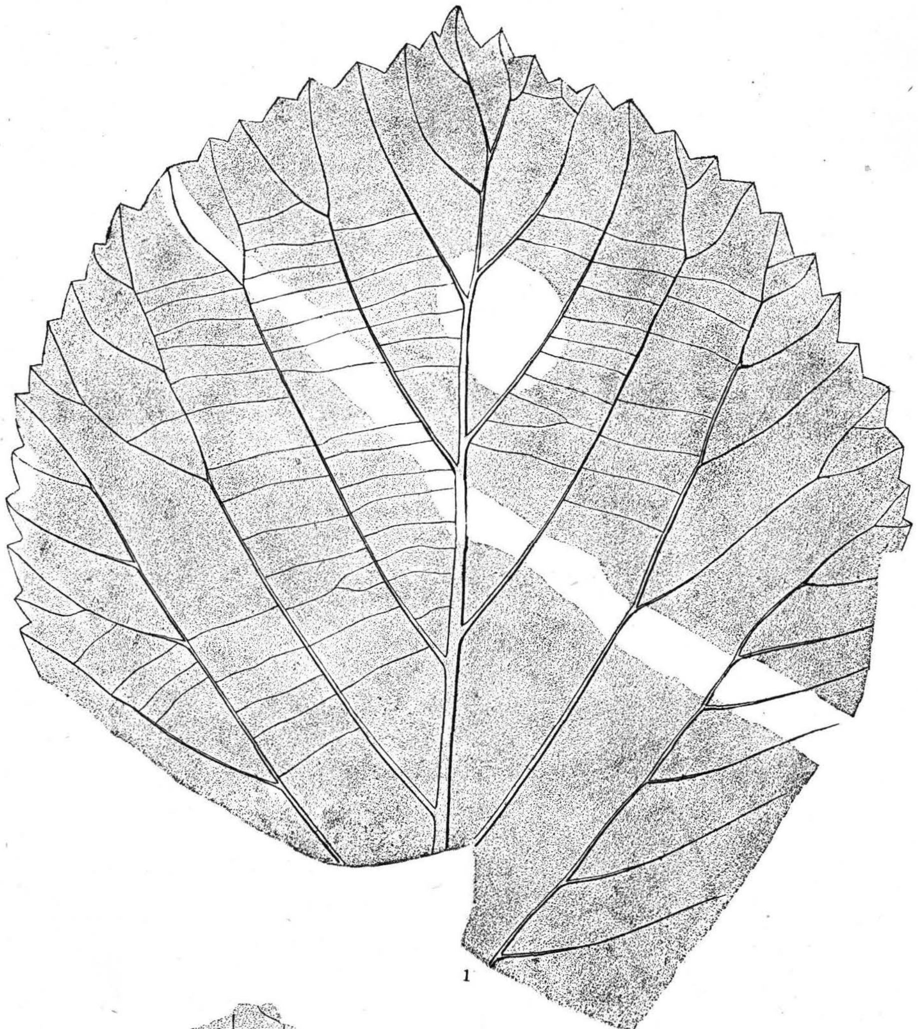
DICOTYLEDONS.

FIG. 1. Liriodendron Laramiense, n. sp. FIGS. 2, 3. Magnolia pulchra, n. sp. FIGS. 4, 5. Diospyros brachysepala, Al. Br. FIGS. 6, 7. D. ficoidea, Lx. FIG. 8. D.? obtusata n. sp.



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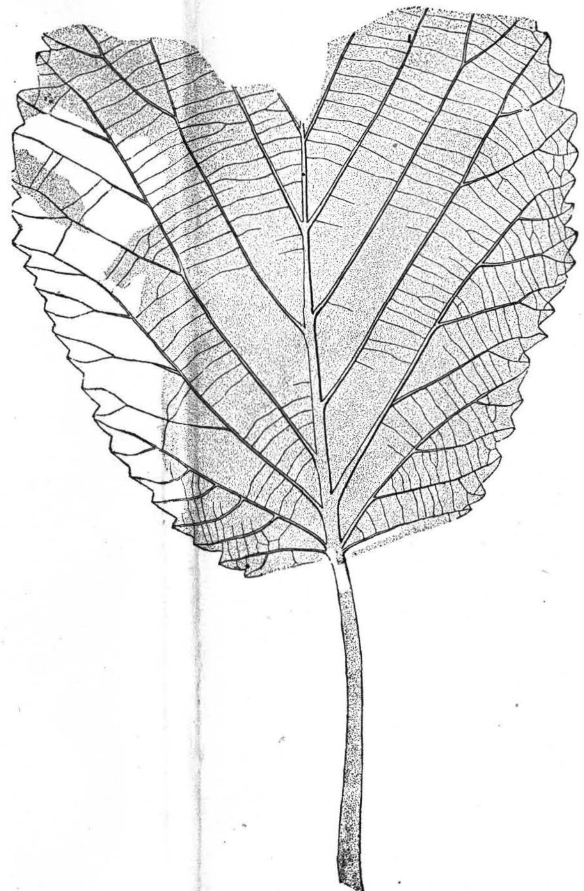

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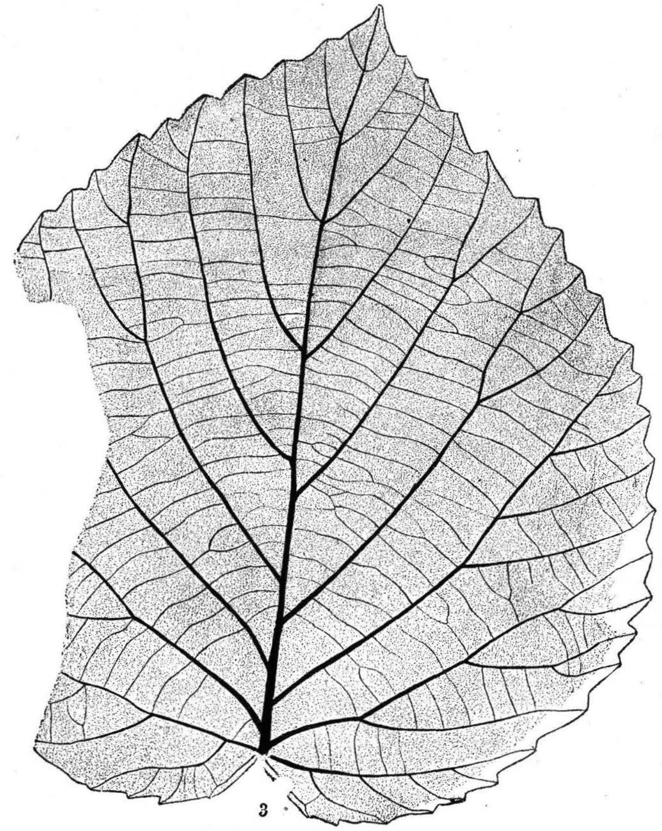

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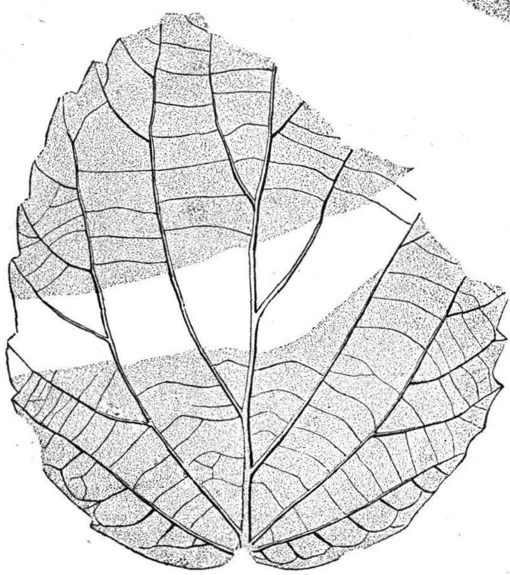

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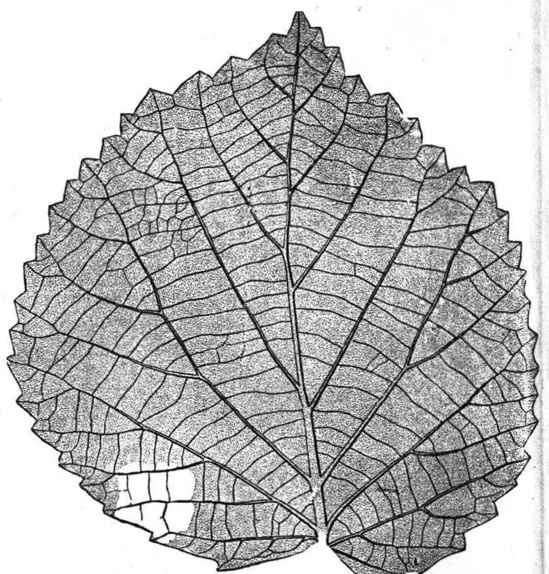

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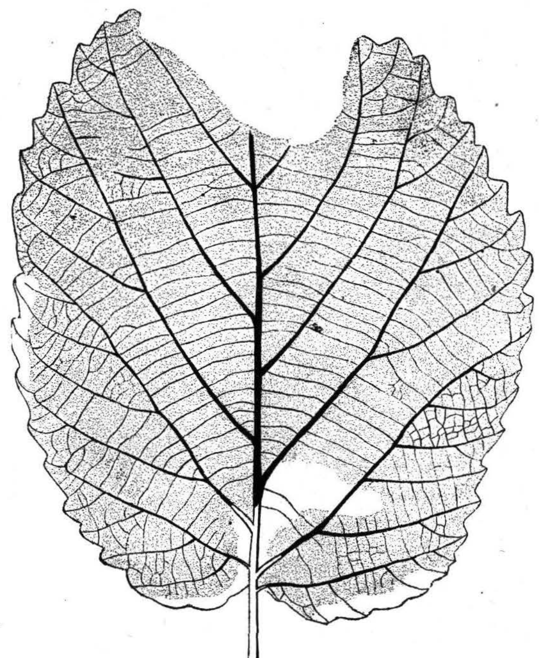

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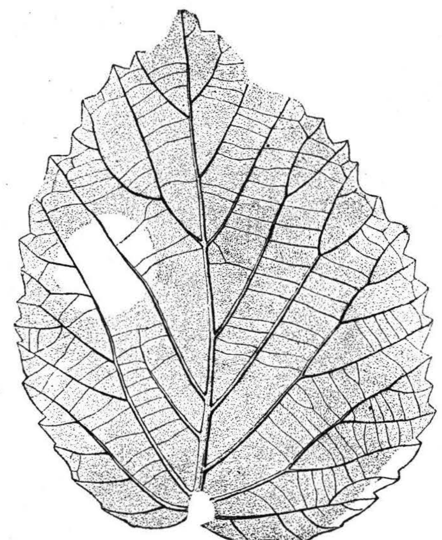

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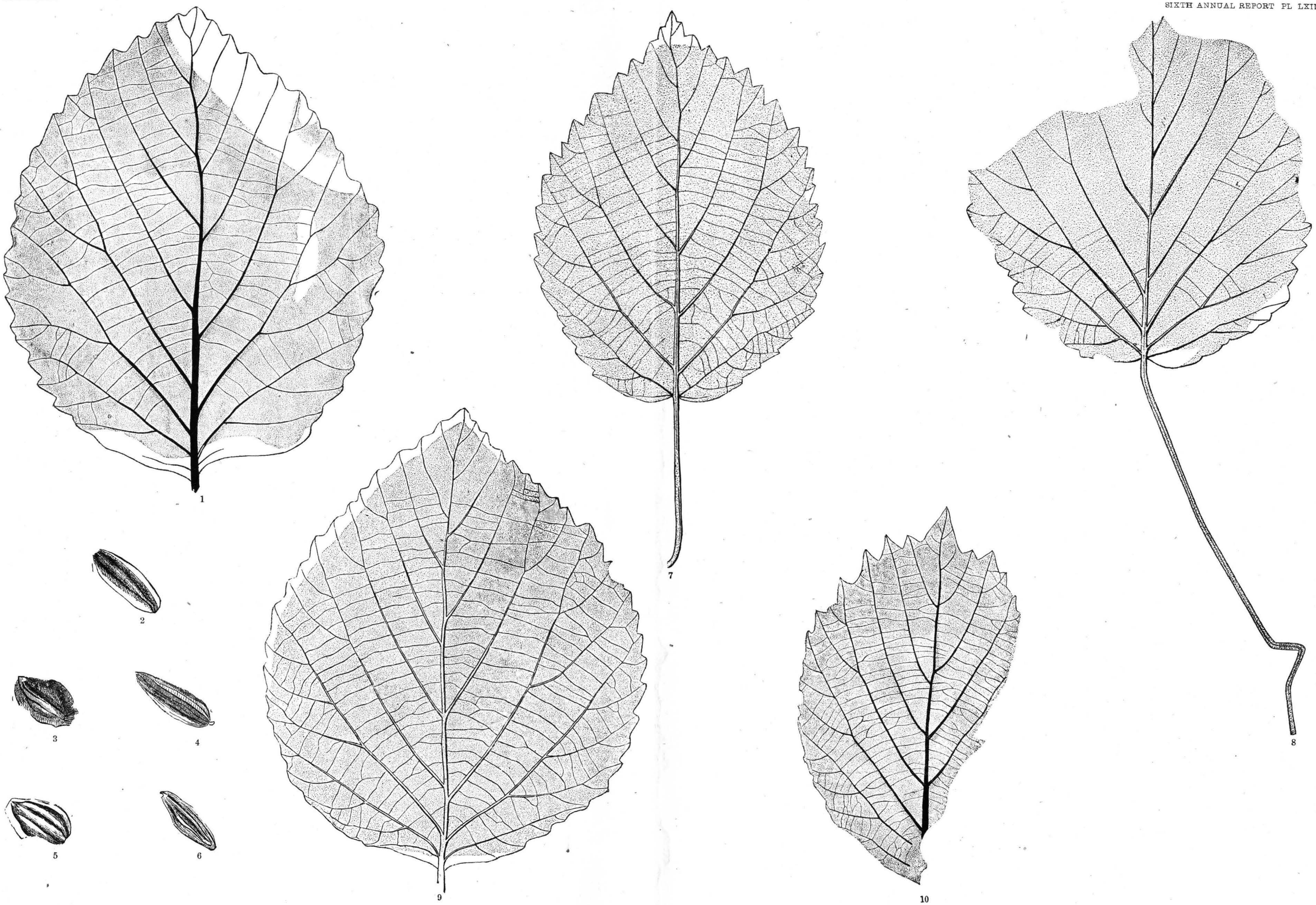
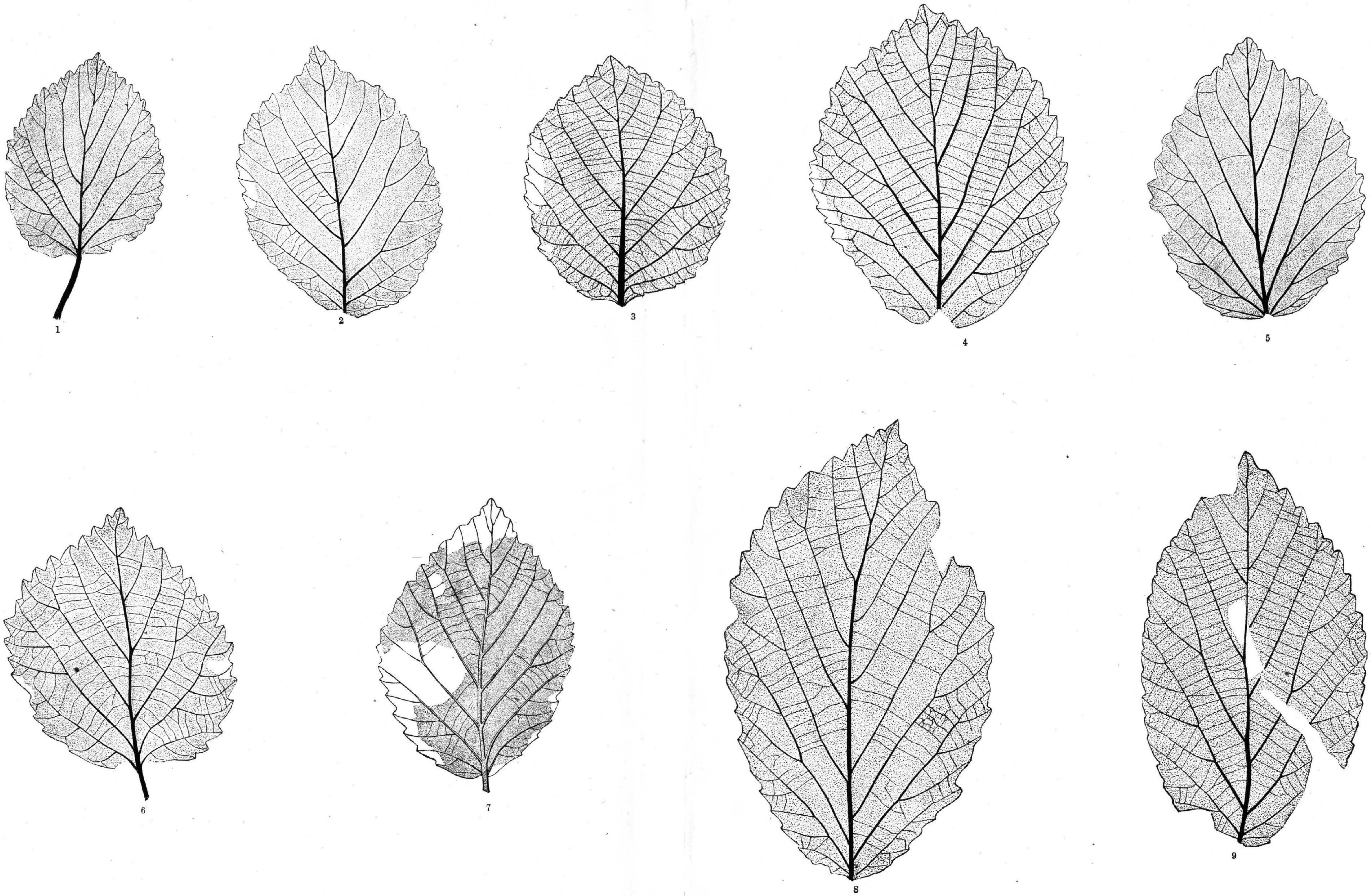
DICOTYLEDONS.

FIGS. 1-7. Viburnum tilioides.



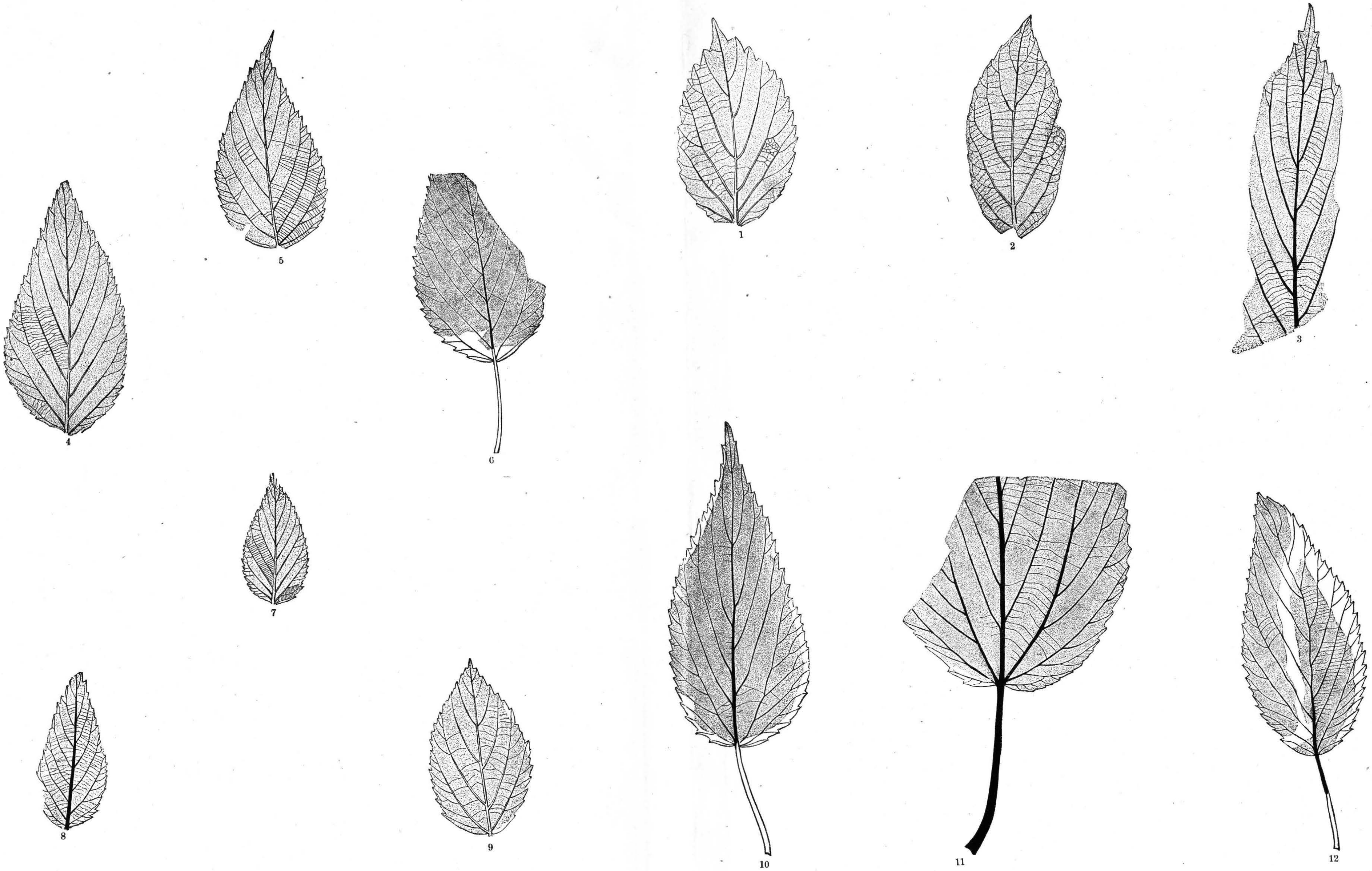
DICOTYLEDONS

FIGS. 1-6. Viburnum tilioides. FIGS. 7-9. V. perfectum, n. sp. FIG. 10. V. macrodontum, n. sp.



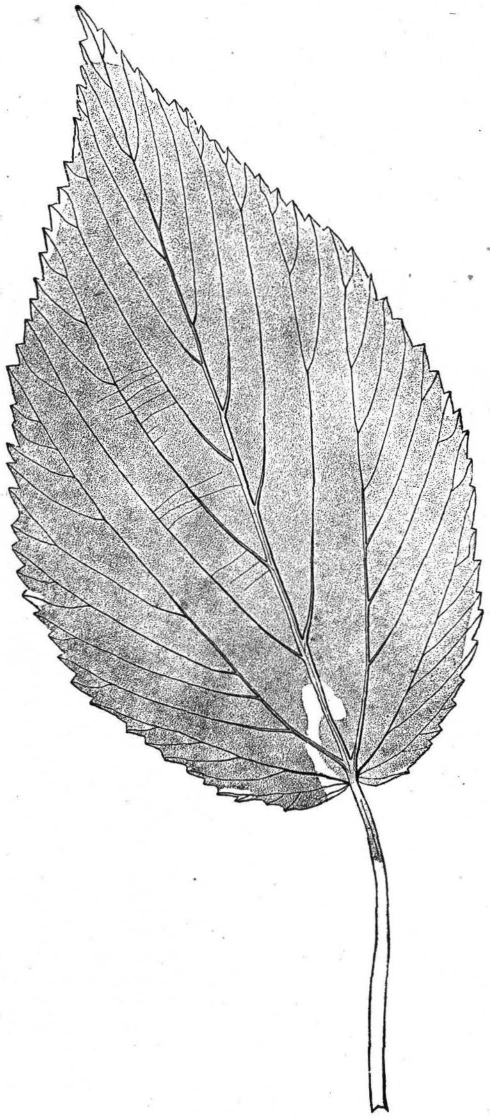
DICOTYLEDONS.

FIGS. 1-4 Viburnum limpidum, n. sp. FIG. 5. V. Whymperi, Heer. FIGS. 6, 7. V. perplexum, n. sp. FIGS. 8, 9. V. elongatum, n. sp.



DICOTYLEDONS.

FIGS. 1, 2. Viburnum oppositinerve, n. sp. FIG. 3. V. erectum, n. sp. FIGS. 4-9. V. asperum, Newby. FIGS. 10-12. V. Newberrianum, n. sp.



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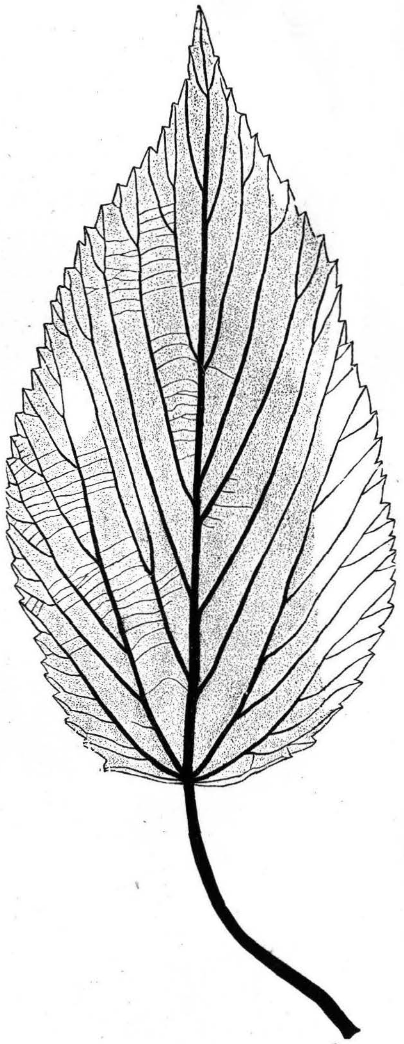

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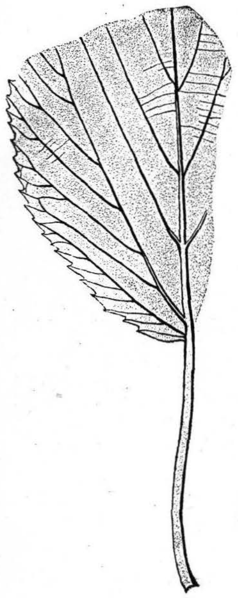

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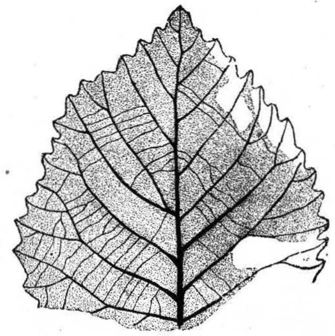

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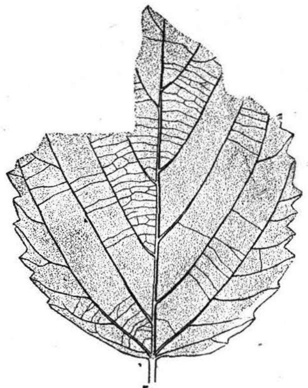

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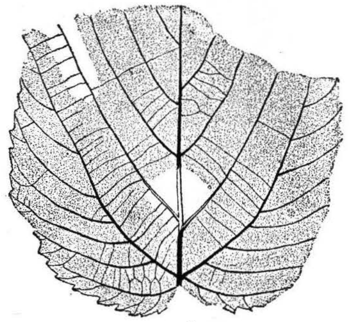

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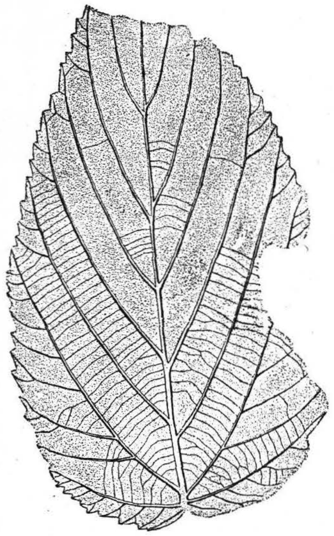

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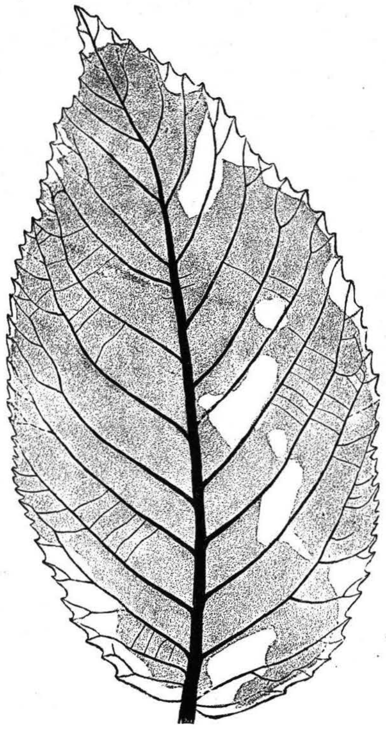

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DICOTYLEDONS.

FIGS. 1–3. **Viburnum Newberrianum, n. sp.** FIGS. 4–6. **V. Nordenskjöldi, Heer.** FIG. 7. **V. betulifolium, n. sp.** FIG 8. **V. finale, n. sp.**

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